BUILDING CONSTRUCTION

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MATERIALS AND TYPES OF CONSTRUCTION

BY

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PREFACE

This book deals with the materials and types of construction used for the various parts of buildings, and not with the structural design except in its qualitative aspects. It is written for sophomore and junior students in civil engineering and architecture; structural engineers, whose experience has been with other types of structures and who wish to become familiar with the construction of buildings; electrical and mechanical engineers, whose work requires a knowledge of the structural make-up of buildings; and for those young men associated with architectural and construction organizations who have not yet gained, through experience, a detailed knowledge of building materials and types of construction.

In the present edition, particular attention has been paid to the recent developments in the knowledge of the behavior of soils supporting foundations; in types of foundations; in the construction of brick cavity walls; in the use of modern connectors and glued-laminated construction for wood trusses, arches, and rigid frames; in flame cutting and the welding of steel, particularly in connection with steel arches and rigid frames; in the construction of arches and rigid frames of reinforced concrete; and in the protection of wood construction from termites.

The newer materials, such as plywood and fiber boards, glass blocks, structural-clay facing tile, structural-steel piles, and asphalt flooring tile, have been given consideration.

Introductory material is given on the insulation of buildings, for reducing heat losses, and on acoustics. These factors have become important in the construction of modern buildings, and it is desirable that the architect and structural engineer understand the problems involved so that they will know when it is necessary to secure expert assistance in those specialized fields, and thus insure satisfactory results.

Particular attention has been paid to the terminology used in building construction. Definitions and illustrations of the many special terms used in this field are included. The book has been thoroughly revised and largely rewritten in order to include the developments which have taken place during the past decade.

The author wishes to acknowledge his indebtedness to the following men for their helpful advice and suggestions on various parts of the

book: Mr. Albert E. Cummings, Dr. Ralph B. Peck, and Dr. Nathan M. Newmark, on soils and foundations; Mr. Arthur J. Boase, on reinforced-concrete construction; Mr. N. S. Perkins, on wood construction; Dr. Floyd R. Watson, on acoustics; Professor Maurice K. Fahnestock, on heat insulation; Dr. Joseph Mattiello, on painting; Professor James J. Doland, for general comments on various parts of the book; and to Professor Clarence L. Eckel, who prepared most of the drawings for the first edition, and Professor Elmer F. Heater, who prepared the additional drawings required for the second edition.

WHITNEY C. HUNTINGTON.

URBANA, ILLINOIS
September 29, 1941

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CHAPTER I

INTRODUCTION

ARTICLE 1. THE BUILDING INDUSTRY

Before considering the various types of buildings and the elements of which they are composed, a general survey of the building industry will be of value. The construction industry is usually considered the second largest industry in this country, being exceeded only by agriculture. The backbone of the construction industry is building construction.

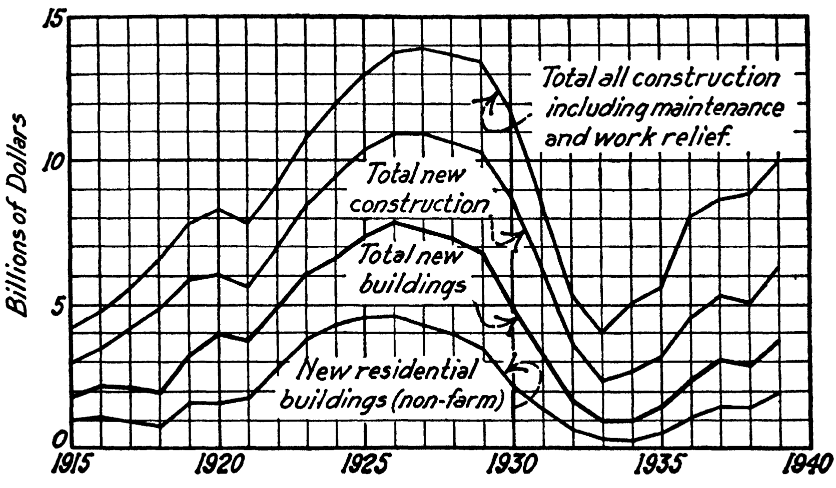


FIG. 1. Construction Activity in the United States

Expenditures on Buildings. The annual expenditures on construction in the United States from 1915 to 1939 are given in Fig. 1, which was prepared from statistics issued by the United States Department of Commerce.[1,2] In this figure are shown the total annual expenditures in the entire country on all construction activity, including maintenance and work relief; on new construction; on new buildings of all types; and on new residential buildings.

[1] Superior numbers refer to items in the References at the end of the chapter.

The maximum annual expenditure on all types of construction and maintenance during the quarter of a century for 1915 to 1939 occurred in 1927 and was about 14 billion dollars. Of this amount about 11 billion dollars was for new construction of all types, about 7½ billion dollars for new buildings, and about 4¼ billion dollars for new residential construction. The national income for the year 1927 is estimated at about 74 billion dollars. The expenditures on construction during that year were, therefore, nearly one-fifth the national income. The national income reached a maximum of about 81 billion dollars in 1929.

During the depression years of the early nineteen thirties, the decline in construction was extremely marked, the minimum expenditures for all types of construction and maintenance being about 4 billion dollars in 1933. Of this about 2⅓ billion dollars was spent on new construction of all types, slightly less than a billion dollars on new buildings and less than ⅓ billion dollars on new residential buildings. The national income for 1933 is estimated at about 42 billion dollars. As would be expected, the decline in construction expenditures was much greater than the decline in the national income, the expenditures for all types of construction being less than one-tenth the national income as compared with one-fifth in 1927. From 1933 to the end of the period, the expenditures on construction showed a steady increase.

The proportionate expenditure on new buildings has varied, during the quarter century covered in Fig. 1, from a maximum of 80 per cent of the total expenditure on all new construction in the year 1922 to a minimum of 37 per cent in 1934. As stated in the preceding paragraph, the proportion of the national income which is expended on construction decreased markedly as the national income decreased, and it has just been shown that the proportion of the total construction expenditures which is devoted to building construction also decreased markedly as the construction expenditure decreased. The net result of these two relationships is that the effect of reductions in national income on new building construction was very pronounced. This combined effect is shown quantitatively by comparing the extreme years of 1927 and 1934. In the former year, the total expenditure on new buildings was 10 per cent of the large national income, while in the latter year it was 2 per cent of the small national income. In 1929 the national income reached a maximum of 81 billion dollars. For that year, the expenditure on new buildings was 8.3 per cent of the national income.

Distribution of Building Expenditures. The most important type of building, so far as building expenditures are concerned, is that built for residential purposes such as dwellings, apartment houses, and hotels.

The expenditure for residential buildings reached a maximum of over 4½ billion dollars in 1926, when it was 58 per cent of the total expenditure for new buildings and 42 per cent of the total expenditure for all new construction. The minimum expenditure for residential buildings occurred in 1934 when it was slightly more than ¼ billion dollars or only 6 per cent of the maximum which occurred in 1926. This quarter-million-dollar expenditure for new residential buildings was 27 per cent of the total expenditure for new buildings in 1934 and 10 per cent of the total expenditure for new construction during that year. These statistics, and others given in Fig. 1, indicate that, while residential construction was the most important item in the new construction expenditures during the prosperous years, this type of building suffered more, proportionately, than other types during the depression years. For that reason, the stimulation of residential construction was considered an important measure in the recovery of the construction industry which, in turn, is an important factor in the economic life of the country.

The distribution of the total expenditures for buildings from 1921 to 1935 inclusive among the various classes of buildings is shown in the following table. These statistics are arranged by 5-year periods and are given for the 15-year period also.[1] The period of this table

DISTRIBUTION OF EXPENDITURES FOR NEW BUILDINGS AMONG VARIOUS TYPES OF BUILDINGS

Type of Building	1921–1925	1926–1930	1931–1935	1921–1935
Residential (Non-farm)	68.3	60.8	51.2	62.9
Commercial	15.0	18.9	22.4	17.6
Factory	8.1	10.1	12.5	9.6
Religious and Memorial	2.5	2.8	3.4	2.7
Educational	1.6	1.9	4.0	2.0
Social and Recreational	3.2	3.8	4.4	3.6
Hospital and Institutional	1.3	1.7	2.1	1.6
Total	100.0	100.0	100.0	100.0

Compiled from "Construction Activity in the United States, 1915–1937," Table 1. U. S. Department of Commerce, Bureau of Domestic Commerce.

includes the post-war years, 1921–1925; the prosperous pre-depression years, 1926–1930, and the depression years, 1931–1935. This table shows again the importance of residential construction, the expenditures on this type of building accounting for from one-half to two-thirds of the total expenditure for new buildings. The most important factor in residential construction is the one-family dwelling, followed closely by

the multi-family dwelling which has increased in importance during the past two decades at the expense of the two-family dwelling. For the 18-year period, 1922 to 1938, about 45 per cent of the families provided with new construction in cities were housed in one-family dwellings, about 15 per cent in two-family dwellings and about 40 per cent in multi-family dwellings, the latter two classifications including buildings with stores. During this period, the proportion of one-family dwellings remained fairly constant, but the proportion of families housed in two-family dwellings decreased markedly in favor of the multi-family dwelling.

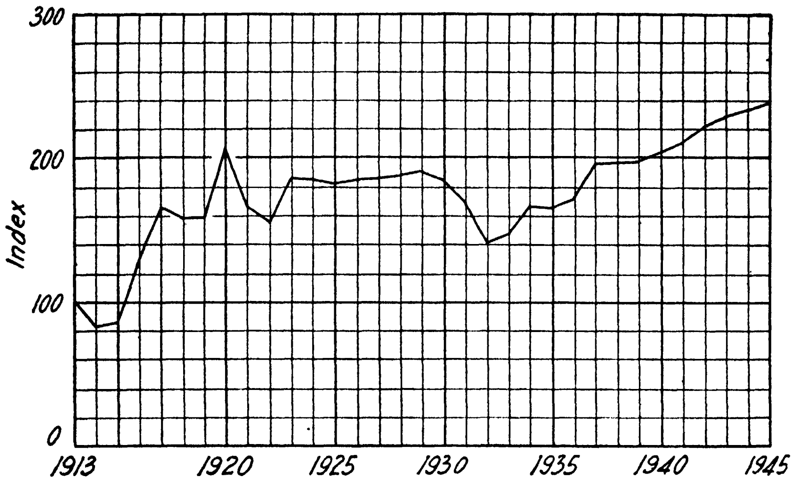


FIG. 2. *Engineering News-Record* Building Cost Index

Yearly Building-Cost Variations. Another important factor in the building industry is the variation in the cost of building from year to year. The cost variations are shown by cost indexes compiled by various agencies following different procedures. Probably the best known building cost index is that shown in Fig. 2, compiled by the *Engineering News-Record.*[3] This index is based on the current prices of structural steel, lumber, and cement, and the wages of skilled labor, each being given appropriate weight. The cost index for 1913 is considered as 100. By consulting Fig. 2, it is seen that building costs reached a maximum in 1920, for the period from 1913 to 1939, when the *Engineering News-Record* building index was 207. The minimum was in 1914 with a value of 92. Since that year the minimum value of the index has never been close to the 1913 value, the other low values being 155 in 1922, 140 in 1932. From 1932 to 1945, the index climbed

steadily to 240. By using 1913 costs as a basis for index values, the true variation from year to year is obtained, but there is a tendency on the part of some to feel that 1913 represents a normal year and that we may expect costs to return to that value eventually. Any serious consideration of the situation will show that this can not be expected and that, from most points of view, it would be undesirable. In considering the building volumes which have accompanied the expenditures shown in Fig. 1, the variation in cost, as indicated by the cost index curve in Fig. 2, must be taken into account.

Building Construction Personnel and Wages. The design and construction of buildings require the services of architects, engineers, contractors, skilled mechanics, laborers, and many other classes of workers such as draftsmen and clerks. In addition to these, in the mines, mills, and factories there are many more employed in producing the raw materials, factory products, and equipment which enter into the construction of buildings. Others are employed in the transportation of these products to the building sites.

According to the 1930 census, there were in this country at that time 22,000 architects and 170,000 builders and building contractors. The numbers reported by this census in the principal skilled trades engaged in building construction were as follows:

NUMBER OF PERSONS IN PRINCIPAL SKILLED TRADES

(According to 1930 Census)

Carpenters	929,426
Painters, glaziers and varnishers	430,105
Laborers and helpers	419,802
Electricians	280,317
Plumbers and gas and steam fitters	237,814
Brick and stone masons and tile layers	170,903
Plasterers and cement finishers	85,480
Structural iron workers	28,966
Roofers and slaters	23,636
Stone cutters	22,888
Total	2,657,665

Between 35 and 40 per cent of the cost of a building is for labor performed at the site. If all labor charges of all classes in the mines, mills, factories, and transportation systems were added to the labor at the site, the total labor cost would be a much larger proportion of the cost, but no estimate of this total is at hand.

Wages for skilled labor vary from 70 cents to $2 per hour, but with a few exceptions the range is from $1 to $1.70. The average for the

country is about $1.45. Wages for common labor vary from 40 cents to 90 cents per hour with the exception of hod carriers who in some cases receive as high as $1.25 per hour. The *Engineering News-Record* average of hourly wages in September 1940 was $1.48 for skilled labor, such as bricklayers, carpenters, and iron workers, and 71 cents for common labor.

Building Costs. Approximate estimates of building costs are commonly prepared on the basis of costs of similar buildings constructed under similar conditions. The units most frequently used in such estimates are the *square foot* of the floor area and the *cubic foot* of volume. The number of square feet of floor area in a building is based on dimensions extending to the outside of the outside walls and the number of cubic feet of volume, or *cubage,* is based on the total volume of space included within the outside surfaces of the outside walls and the roof and the bottom surface of the basement floor. The cubage includes dormers, penthouses, and other enclosed spaces but does not include courts or light shafts open at the top or open porches. A standard procedure adopted by the American Institute of Architects is given in A.I.A. Document 239. See also Bureau of Standards Report BMS 91.

Type of construction, quality of workmanship, and many other factors which will not be mentioned here affect the cost of buildings, but important among these factors are the conditions which prevail in the locality in which a building is constructed and the prices which prevail at the time a building is constructed. Price fluctuations which occurred during the period from 1913 to 1940 are shown by the cost index curve in Fig. 2.

In 1940, the cost of well-constructed non-fireproof two story dwellings varied from $3 to $6 per square foot of floor area including the area of the basement floor, and the cost per cubic foot from about 30 to 60 cents. The cost of well-constructed fireproof school buildings, apartments, office buildings, hotels, and hospitals varied from $6 to $12 per square foot of floor area and from 40 cents to $1 per cubic foot, with most buildings falling between 50 and 65 cents per cubic foot. Ware houses, garages, factories, field houses, and similar buildings without interior finish and with a small amount of plumbing varied in cost from 20 to 30 cents per cubic foot.

About two-thirds of the floor space of a tall office building is available for rental purposes, the remainder being occupied by corridors, elevators, toilet facilities, mechanical equipment, etc., and it requires about 18 cu. ft. of gross volume to produce one square foot of rentable floor area.

The best cost data are those compiled by architects and engineers

from their own experience and for their own use. Other data can be obtained from architectural and engineering periodicals. Bids should never be based on estimates of this type but only on carefully prepared detailed estimates.

Economic Height. The height of buildings has been restricted by building codes for various reasons but for given conditions there is a height which will produce a maximum percentage of annual net return on the investment in a building and the land it occupies over the period covered by the life of the structure. Considering a structure of the office building or hotel type, the income from which is derived from renting the quarters provided, the amount of rentable space which it is necessary to erect on the site to provide the maximum percentage of net return will depend upon the cost of the land. If this were the only factor, if there were no legal or engineering limitations on the height, and if all of the space provided could be rented, the percentage of net return would continue to increase with the height. However, the costs per square foot of rentable floor area of many parts of a building increase as the height increases. These increases are only partially offset by those which tend to decrease. Some are independent of the height. The following summary of the more important factors which affect the economic height are given in "The Skyscraper" by W. C. Clark and J. L. Kingston:[4]

1. Value of the land.
2. Size and shape of plot.
3. Legal restrictions.
4. Efficiency of architectural design and layout.
5. Building factors showing tendency to increasing cost.
   Structural steel, elevators, brickwork, plumbing and water supply, heating and ventilating, electric light and power wiring, total mechanical equipment, permanent interior partitions, windows and glazing.
6. Building factors showing tendency to decreasing cost.
   Roofing, excavations and foundations.
7. Building factors showing tendency to constant cost.
   Interior finish, concrete floors, exterior finish.
8. Absorption of rentable floor area by elevators and other service facilities, increases with height.
9. Level of construction costs.
10. Variations in rental values of floors at various heights.
11. Variation in operating costs at various heights.

As the result of studies of economic height made in the above reference, it was concluded that in 1930 the economic height of buildings erected in New York City on a lot of 200 ft. by 405 ft. for land costs of $100 to

$300 per square foot was 63 stories and for a land cost of $400 per square foot was 75 stories. The proportionate increase in net return due to increases in height was, of course, less for the lower land values than for the higher land values. In this reference it is stated that the physical or engineering height limit is about 2000 ft. because of the weight of the elevator cables and the capacity of the average human ear drum to withstand the vibrations in an elevator cab travelling at a speed exceeding 1500 ft. per min., which is considered a necessity for adequate service.

Outstanding Buildings. The highest building in the world for the period from 1914 to 1929 was the Woolworth Building in New York City with 60 stories and a height of 792 ft.; but both the Bank of Manhattan Building with a height of 70 stories or 927 ft. and the Chrysler Building with a height of 77 stories or 1046 ft., to the tips of the flagpoles, overtopped the Woolworth Building in 1930. The Empire State Building, completed in 1931, has a height of 85 stories or 1245 ft. Its volume is 36 million cu. ft. and its rentable floor area is 2 million sq. ft. The cost of the Empire State Building was about $35,000,000, exclusive of the land which cost $17,500,000. It provides office space for about 20,000 people. The Merchandise Mart in Chicago has a floor area of over 4,000,000 sq. ft. or 93 acres. This is the largest floor area of any building in this country. The deepest foundations for any building in the country are those for the piers supporting the tower of the Cleveland Union Terminal Building which rest on rock 262 ft. below the curb level. One of the longest roof spans is that of the three-hinged arches of the Goodyear Hangar at Akron, Ohio, which is 325 ft.

The United States is the home of the skyscraper, but other countries have their lofty buildings. Ulm Cathedral in Germany, which was started in 1377 but not completed until 1890, has towers 528 ft. high; Cologne Cathedral in the same country was started about 1300 and completed in 1880 with spires 512 ft. high. The top of the cross on the dome of St. Peter's in Rome, completed in 1564, reaches a height of 435 ft. Eiffel Tower in Paris, completed in 1889, is 1000 ft. high and the Palace of the Soviets, a tower building on which construction was started in 1935 in Moscow, Russia, will be the highest structure in the world with a height of 1375 ft.

ARTICLE 2. CLASSIFICATION AND GENERAL REQUIREMENTS FOR BUILDINGS

Building Codes. Types of construction, quality of materials, floor loads, allowable stresses, and all other requirements relating to buildings

are covered by building codes. Each city has its own building code to which the buildings of that city must conform. There is great lack of uniformity in these codes even where there is no reason for variation. For identical conditions, the floor loads, the allowable stresses, the wall thickness, and many other items vary through a wide range. This results either in a waste of material or a sacrifice of safety and leads to confusion among architects and engineers whose practice is not confined to one city.

Many agencies are at work to improve this situation. The Building Code Committee of the Department of Commerce has published reports on several phases of the problem; the Pacific Coast Building Officials Conference has published a Uniform Building Code; the National Board of Fire Underwriters has published a Recommended Building Code; and the American Society for Testing Materials has published numerous specifications for materials. Frequent reference will be made to these publications.

Authority for Building Codes. The legal principles involved in the enforcement of building code requirements are outlined in the following paragraph quoted from a report of the Building Code Committee of the Department of Commerce:[5]

Code requirements depend on what is known as the "police power" for enforcement. The police power is that inherent power of government which protects the people against harmful acts of individuals, so far as matters of safety, health, morals, or the like are concerned; and unless a code requirement can be shown to be necessary for such protection, it will not be supported by the courts. The limits of the police power have never been defined lest its flexibility be lost, but, in general, are gradually being extended. It has at times received very broad interpretation, but the usual result when a borderline case is brought into court is to defeat the requirement and to undermine the authority of the building official. Authority to exercise the police power is delegated by the state authorities to cities and a police power regulation enacted by the state legislature will, in general, outweigh a conflicting provision enacted by local authorities.

Classification According to Construction. Building codes commonly classify buildings according to the type of construction and according to use or occupancy. The most important factor in the classification according to type of construction is the resistance to fire exposure. In classifying buildings in this manner it is therefore necessary to have some measure of the performance of walls, columns, floors, and other building members under fire-exposure conditions. As stated in the Appendix to the "Building Code" of the National Board of Fire Underwriters,[6]

To do this it is necessary that the fire-resistive properties of materials and assemblies be measured and specified according to a common standard expressed in terms which are applicable to a wide variety of materials, situations, and conditions of exposure.

The *Standard fire test* consists of exposing samples of the material or building members to be tested to a fire of specified intensity and, in most cases, to a fire-hose stream when the sample is in the heated condition. Performance is defined as the period of resistance to standard exposure elapsing before the first critical point in behavior is observed and is expressed in hours. For example, a material is given a two-hour rating if it withstands the test for a period of two hours. The details of the test are given in Appendix C of the "Building Code" of the National Board of Fire Underwriters.[6] This publication may be obtained from that organization. Most common building materials and types of members have been tested and rated so it is not necessary to make fire tests in connection with the design of individual buildings. The fire-resistance ratings of a large number of types of construction for walls, partitions, columns, beams, girders, floors, roofs, etc., are given in Recommended Minimum Requirements for Fire Resistance in Buildings, Building Code Committee, Dept. of Commerce.[7]

Fire-hazard periods of from one to four hours, for average conditions, are given in codes. These are based on tests conducted by the Bureau of Standards which showed that the duration of a fire was affected by the weight of the combustible materials in a building, as shown in the following table:

Relations between Weight of Combustible Contents and Fire Duration

(From Tests by Bureau of Standards)[7]

Combustible Contents: Weight of Furniture, Flooring, Trim, etc., Load in Lb. per Sq. Ft.	Maximum Fire Hazard: Destructive Effect Equivalent to Standard Fire Test, Fire Duration in Hours
10	1
15	1½
20	2
30	3
40	4½
50	6
60	7½

Where the contents are such that the periods of fire duration, as indicated by this table, are greater than the periods included in a code

for average conditions, the larger values should be used. For information concerning the limitations in these data the reference should be consulted.

The classification of buildings according to construction as given by the National Board of Fire Underwriters may be considered as typical and is as follows:

1. Fireproof construction.
2. Semifireproof construction.
3. Heavy timber construction.
4. Ordinary construction.
5. Frame construction.

These classes are defined as follows:

Fireproof construction is that in which walls are of approved masonry or reinforced concrete and the structural members of which have fire-resistive ratings sufficient to withstand the hazard involved in the occupancy, but not less than a four-hour rating for bearing walls, fire walls, party walls, isolated piers, columns, and wall-supporting girders; a three-hour rating for walls and girders other than already specified and for beams, floors, roofs, and floor fillings; and a two-hour rating for fire partitions.

Semifireproof construction is similar to fireproof construction except that bearing walls, isolated piers, columns, and wall-supporting girders may have a three-hour rating instead of a four-hour rating and exposed beams, floors, and floor fillings may have a two-hour rating instead of a three-hour rating.

Heavy timber construction is that in which walls are of brick, concrete, or reinforced concrete; and in which the interior structural elements, including posts, floors, and roof construction, consist of heavy timbers with smooth flat surfaces assembled to avoid thin sections, sharp projections, and concealed or inaccessible spaces; and in which wall-supporting girders and structural members of steel or reinforced concrete, if used in lieu of timber construction, have a fire-resistance rating of not less than three hours.

This type of construction is often called *mill construction* or *slow-burning construction.*

Ordinary construction is that in which the exterior walls are of approved masonry or reinforced concrete; and in which the interior structural members are wholly or partly of wood of smaller dimension than required for heavy-timber construction, or of steel or iron that is not protected as required for fireproof construction or semifireproof construction.

Frame construction is that in which exterior or party walls are wholly or partly of wood. This type includes buildings with brick or stone veneer, stucco or sheet metal over wood exterior walls.

No building is really fireproof. The fire-exposure conditions may be such as to cause considerable damage to the highest type of construction, particularly if surrounding buildings are burning. The term *fire-resistive* more nearly defines the actual situation but, since the term fireproof is so widely used, it is commonly adopted by building codes. All steel beams, girders, columns, lintels, and reinforcing bars must be protected from over-heating in case of fire, by approved fireproofing materials, for the strength of steel is greatly reduced at temperatures which may be reached in a severe fire. The materials used for protecting structural steel may be brick masonry, concrete, gypsum tile, and hollow clay tile, the thickness required varying from 2 in. to 4 in. depending on the materials used and other conditions. No woodwork or other combustible material may be used in the construction of fireproof buildings except wood flooring, interior doors, and windows with their frames, trim, and casings. Wooden strips, blocks, or frames may be provided for nailing flooring and casings, if such members are embedded in an incombustible material. In the best class of fireproof buildings no wood whatever is used, the floors being of fireproof material and all doors, door and window frames, casing, etc., being of metal. Wire glass in metal frames is used in the windows and, if the exposure is severe, fire shutters may be required.

The term *mill construction,* which is often used instead of *heavy timber construction,* had its origin in New England where heavy timber construction was developed many years ago to decrease the fire hazard in textile mills. The reason for calling this type of construction *slow-burning* is obvious. Wood columns are commonly required to be at least 8 in., nominal, in any dimension and to have the corners rounded or chamfered and wood beams must not be less than 6 in. wide by 10 in. deep. Steel or cast-iron structural members must be protected against fire as in fireproof construction. Timber floors must be at least 3 in. thick with 1-in. flooring. In the designing of buildings of this type, great care is used in avoiding unprotected openings which would enable fire to travel from one floor to another or from one room to another on the same floor. Stairways, elevator shafts, and openings are carefully protected. *Automatic sprinklers,* which automatically come into play if the temperature in a portion of a building so equipped rises to an abnormal level, are commonly placed on the ceilings of buildings of this type.

Buildings may also be classified according to type of construction

into buildings with bearing wall construction and buildings of skeleton construction. In *bearing wall construction* the loads are transmitted to the foundations by walls, while in *skeleton construction* all loads are transmitted to the foundations by a rigidly connected framework of steel or reinforced concrete beams, girders, trusses, and columns, with enclosing walls, partitions, and floors supported at each floor level by the structural frame, as illustrated in Figs. 3 and 4.

Classification According to Use. Building codes classify buildings according to use or occupancy in various ways. The classification of the National Board of Underwriters, which follows, may be considered as typical:

1. Public buildings.
2. Institutional buildings.
3. Residence buildings.
4. Business buildings.
5. Storage buildings.

These classes are defined as follows:

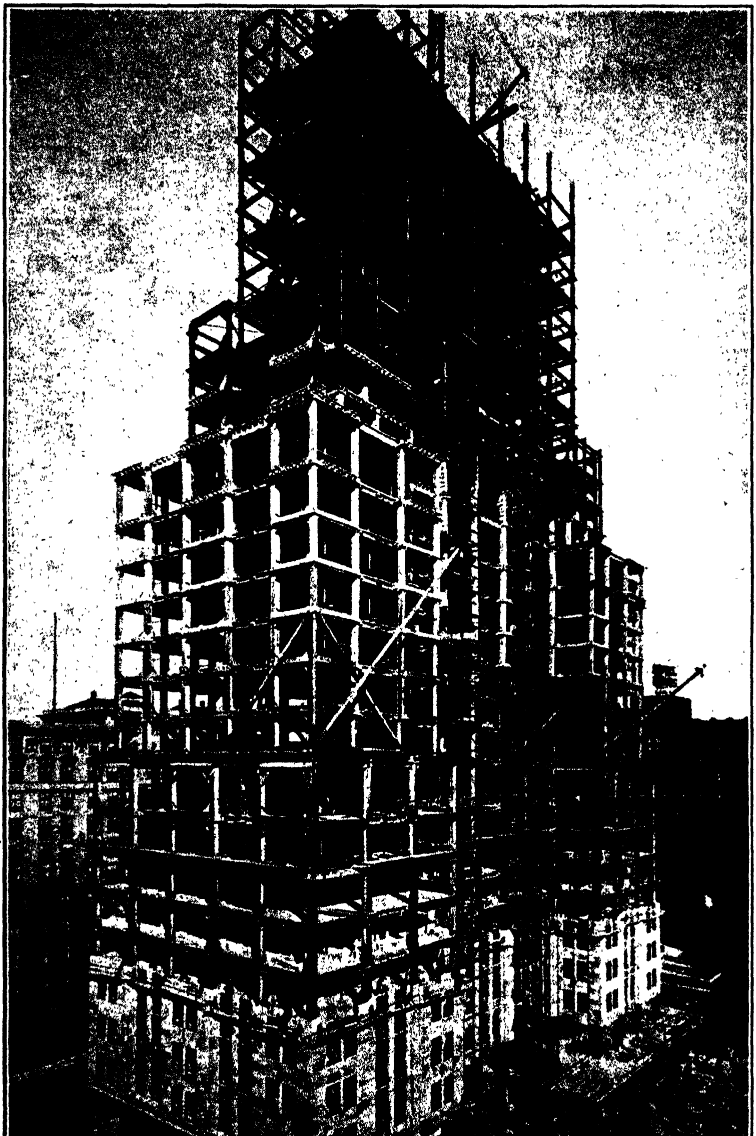
Public buildings are those in which persons congregate for civic, political, educational, religious, social, or recreational purposes. This class includes court houses, schools, colleges, libraries, museums, exhibition buildings, lecture halls, churches, assembly halls, lodge rooms, dance halls, theaters, bath houses, armories, and recreation piers.

Institutional buildings are those in which persons are harbored to receive medical, charitable, or other care or treatment, or in which persons are held or detained by reason of public or civic duty, or for correctional purposes. This class includes, among others, hospitals, asylums, sanitariums, fire houses, police stations, and jails.

Residence buildings are those, except institutional buildings, in which sleeping accommodations are provided. Included here are dwellings, tenements, multi-family houses, hotels, lodging houses, dormitories, convents, studios, and club houses.

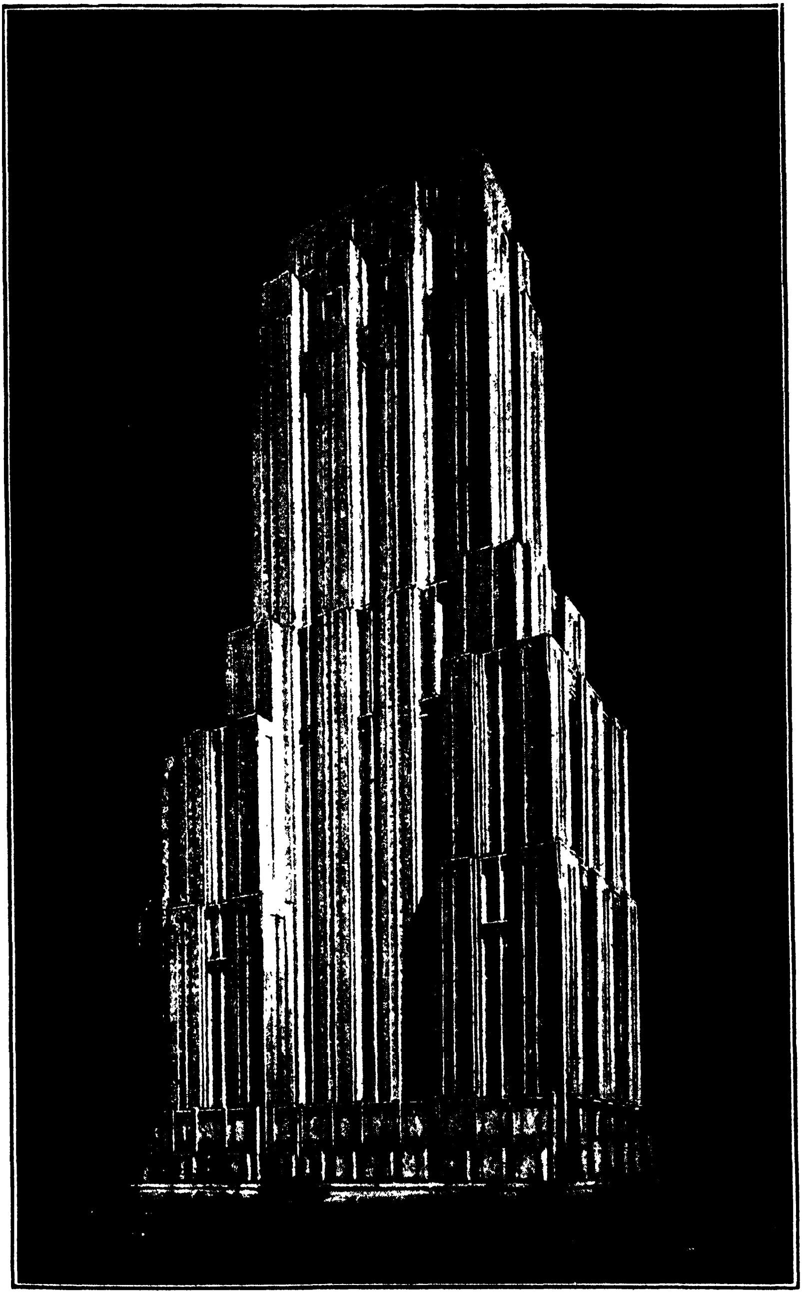
Business buildings are those occupied for the transaction of business; for the rendering of professional services; for the display, sale, or storage (if not used exclusively for storage) of goods, wares, or merchandise; for the supplying of food, drink, or other bodily needs or comforts; or for the performance of work or labor; and including such buildings as office buildings, stores, markets, restaurants, factories, workshops, and laboratories.

Storage buildings are those used, except for purely display purposes, for housing airplanes, automobiles, carriages, railway cars, or other vehicles of transportation; for sheltering horses, livestock, or other



The Lundoff-Bicknell Co., Contractors. Holabird and Root, Architects

FIG. 3. Palmolive Building, Chicago, Ill., Under Construction



Holabird and Root, Architects

Fig. 4. Palmolive Building, Chicago, Ill.

animals; or exclusively for the storage of goods, wares, or merchandise, not excluding in any case offices incidental to such uses; and including, among other buildings, garages, carriage houses, stables, barns, hangars, storage warehouses, freight depots, and grain elevators.

Relation between Use, Height, Area, Location, and Construction. The seriousness of a fire is determined largely by the amount of combustible material present. For the same occupancy and type of construction, the amount of combustible material in a building is determined largely by its height and its ground area. Also the difficulty in extinguishing a fire increases with the height and area of a building and, finally, occupants of a building must have an opportunity to escape at the time of fire. For these reasons, building codes place limits on the height and area of all non-fireproof buildings. However, there are other factors which may make it desirable to limit the height of fireproof buildings also. Among these may be mentioned the effect of tall buildings upon the natural lighting and ventilation of adjoining buildings, their effect on street traffic, and their effect on the aesthetic appearance of the city as a whole. Some of these reasons have been the subject of much debate, particularly the effect of tall buildings on street traffic.[4] Many cities place a maximum height to which buildings may be built regardless of the type of construction used or the area of the ground covered, a common limit being 125 ft., but sometimes no limit is placed on the height or area of buildings of fireproof construction.

The height restrictions in force in New York City are worthy of special attention on account of the effect they have had upon the architectural style of tall buildings throughout this country. The height to which a building may be carried is based primarily on the width of the street upon which it fronts, but portions of the building which are set back from the street line may be carried to greater heights, based upon the amount of the set-back. The city is divided into eight districts. In the district with the most severe restrictions, the height must not exceed one-quarter times the width of the street; but for each 2 ft. that the building or portion of it sets back from the street line, 1 ft. may be added to the height of the building or the portion of it which is set back. In the district where the height restrictions are the most liberal, a building may be carried to a height of two and one-half times the width of the street and for each foot which the building or portion of it sets back from the street line, 5 ft. may be added to the height of the building or the portion of it which is set back. The requirements in the other six districts lie between those of the districts just given. In all districts, if the area of the building is reduced so that, above a given level, it covers not more than 25 per cent of the area of the lot, that

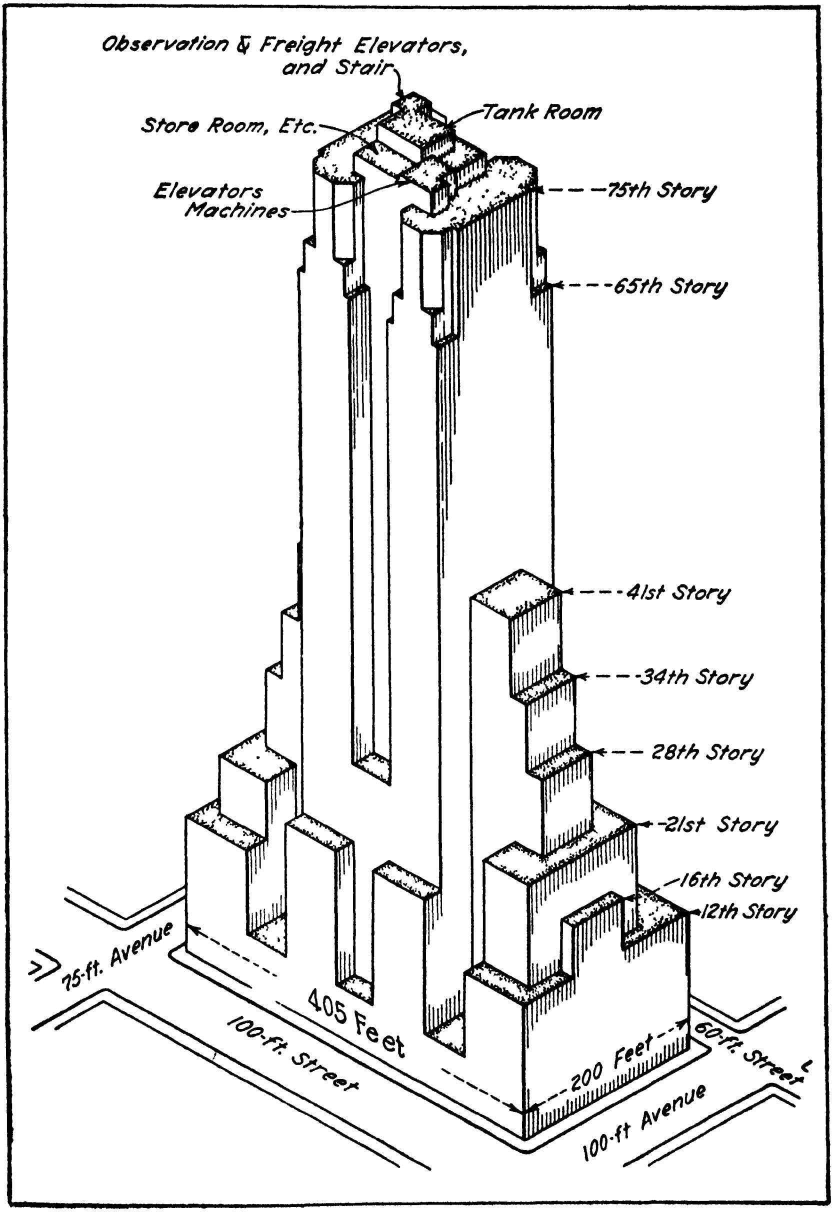


Fig 5. Set-Back Building

portion of the building which is above such a level is not limited in height. The code contains several other exemptions from the height restrictions. The restrictions on height were adopted to provide light and air for the buildings and the streets. Little thought was given to their effect on the appearance of the buildings but the set-back has led to the development of a style of architecture for tall buildings which is greatly superior in appearance to the styles which existed before the restrictions were adopted. The set-back is being used in all parts of the country even where the local codes do not have such requirements.

The effect of these height restrictions on the mass of tall buildings is illustrated in the isometric drawing of Fig. 5, prepared from a similar drawing by Kingston and included in " The Skyscraper " by Clark and Kingston.[4]

Cities usually set aside an area within which the building requirements are more severe than in other areas. This is done for the purpose of fire protection, and the boundaries of this area are known as the *fire limits.* Such areas would naturally include the business and manufacturing districts and sufficient surrounding areas to protect those districts. Frame structures are usually not permitted within fire limits, exception being made for small sheds, garages, etc.

In general, the limitations on the height and ground area covered become more severe as the fire-resistance properties of the buildings decrease.

The limitations in height and ground area covered, as indicated in the " Building Code " of the National Board of Fire Underwriters, are given in the table on page 19 and will serve as examples.

Various qualifying clauses and exceptions are included in the code of the Underwriters, among which are the following: No limit is placed on the area of a building if it is divided by fire walls into areas not larger than those given; if automatic sprinkler systems are provided, certain increases in the height and area are permitted; church spires, elevated tanks, and chimneys are not considered parts of a building, so far as restrictions are concerned; the area restrictions given in the table are for buildings fronting on only one street and are increased if a building faces on two streets and still further increased if a building faces on three streets because of better opportunities offered for extinguishing fires; buildings whose structural members are steel, which is not protected against the high temperatures which might exist in case of fire, are limited in height to one story. Asylums, detention buildings, hospitals, jails, nurseries are required to be of fireproof construction for obvious reasons.

In general, a building is not permitted to cover the entire lot area, but

LIMITS OF HEIGHT AND GROUND AREA
(According to Building Code of National Board of Fire Underwriters)

Occupancy	Type of Construction	Maximum Height	Maximum Area
Public	Fireproof	Not specified	None
	Semifireproof	75 ft.	None
	Heavy timber	35 ft. or 2 stories	6,500 sq. ft.
	Ordinary	35 ft. or 2 stories	5,000 sq. ft.
	Frame	30 ft. or 1 story	5,000 sq. ft.
Institutional	Fireproof	Not specified	None
	Semifireproof	75 ft.	None
	Heavy timber	35 ft. or 2 stories	6,500 sq. ft.
	Ordinary	35 ft. or 2 stories	5,000 sq. ft.
	Frame	35 ft. or 1 story	5,000 sq. ft.
Residence	Fireproof	Not specified	None
	Semifireproof	75 ft.	None
	Heavy timber	75 ft.	6,500 sq. ft.
	Ordinary	45 ft. or 3 stories	5,000 sq. ft.
	Frame	35 ft. or 2 stories	5,000 sq. ft.
	Dwellings	3 stories	
Business	Fireproof	Not specified	None
	Semifireproof	75 ft.	10,000 sq. ft.
	Heavy timber	75 ft.	6,500 sq. ft.
	Ordinary	55 ft.	5,000 sq. ft.
	Frame	25 ft.	5,000 sq. ft.
Storage	Fireproof	Not specified	None
	Semifireproof	55 ft.	10,000 sq. ft.
	Heavy timber	35 ft.	6,500 sq. ft.
	Ordinary	35 ft.	5,000 sq. ft.
	Frame	25 ft. or 1 story	5,000 sq. ft.

uncovered spaces are provided to supply light and air to the building. These spaces must be open to the sky from the top of the second-story window sills. The portion of the lot area which must be given over to uncovered spaces depends upon whether or not the building is on a corner lot, upon the use of the building, and upon its height. A hotel or similar building on a corner lot must devote 15 per cent of the total lot area to uncovered spaces if its height does not exceed 75 ft. or 6 stories with an increase of 2 per cent for each additional story up to 125 ft. in height. A hotel not on a corner lot must have uncovered spaces equal to 20 per cent of the total lot area if its height does not exceed 75 ft. and 25 per cent if its height is over 75 ft. The requirements

for open spaces for buildings for other purposes are only about half as large as those for hotels or similar buildings.

ARTICLE 3. LOADS CARRIED BY BUILDINGS

The loads which buildings are called upon to carry may be divided into three groups: dead load, live load, and lateral loads.

The *dead load* includes the weight of all parts of the building such as walls, permanent partitions, floors, and roof. Temporary or movable partitions which may be moved to suit the needs of the occupants are usually classed as live loads.

The *live load* includes the weight of all the furniture, equipment, occupants, stored material, snow which may accumulate on the roof of a building, and temporary or movable partitions.

The *lateral loads* include wind, earth pressure, water pressure, and earthquake shocks. Lateral loads are sometimes classed as live loads.

The minimum loads for buildings of various occupancies or uses are specified by building codes. The requirements of these codes vary through a wide range for identical conditions. In order to bring about greater uniformity the Building Code Committee of the Department of Commerce has made a study of this problem. The results of this study are given in a report of the committee entitled "Minimum Live Loads Allowable for Use in Design of Buildings."[9] The following minimum requirements for live floor and roof loads and for wind loads are abstracts from this report:

Floor Loads.

	Lb. per Sq. Ft.
Human Occupancy:	
Rooms of private dwellings, hospitals, hotels	40
Offices, rooms with fixed seats such as in churches, school class rooms, and theaters	50
Aisles, corridors, lobbies, banquet rooms, assembly halls without fixed seats, gymnasiums	100
Industrial and Commerical Occupancy:	
Storage (general)	250
Storage (special)	100
Manufacturing (light)	75
Printing plants	100
Wholesale stores (light merchandise)	100
Retail salesrooms (light merchandise)	75
Stables	75
Garages for all types of vehicles	100
Garages for passenger cars only	80
Sidewalks, 800 lb. concentrated or	250

The live loads for which each floor or differing parts thereof of a commercial or industrial building is designed shall be certified by the building official and shall be conspicuously posted in that part of each story where they apply, using durable metal signs. The occupant of the building shall be responsible for keeping the actual loads below the certified limits. Adequate measures shall also be taken by the building official to insure that these loadings are not exceeded.

Roof Loads (In pounds per sq. ft. of horizontal projection).

For slopes of 4 in. or less per ft.	30
For slopes of from 4 in. to 12 in. per ft.	20

For slopes of over 12 in. per ft. no vertical load need be assumed but provision shall be made for a wind force acting normal to the roof surface of 20 lb. per sq. ft. of such surface.

Reductions in Live Loads. Except in buildings for storage purposes the following reductions in assumed total floor live loads are permissible in designing all columns, piers or walls, foundations, trusses, and girders:

	PER CENT
Carrying one floor	0
Carrying two floors	10
Carrying three floors	20
Carrying four floors	30
Carrying five floors	40
Carrying six floors	45
Carrying seven or more floors	50

[Any small area in a building may be subjected at any time to the specified floor load but, except in the case of buildings used for storage purposes, there is little possibility of a large area's carrying a load of this same intensity. The average floor load will decrease as the area included becomes larger.]

For determining the area of footings the full dead loads plus the live loads, with the reductions figured as permitted above, shall be taken except that in buildings for human occupancy a further reduction of one-half the live load as permitted above may be used.

Wind Load. For purposes of design the wind pressure upon all vertical plane surfaces of all buildings and structures shall be taken as not less than 10 lb. per sq. ft. for those portions less than 40 ft. above ground and not less than 20 lb. per sq. ft. for those portions more than 40 ft. above ground. (Special provision is made for sprinkler tanks, sky signs, etc.)

Where it shall appear that a building or structure will be exposed to the full force of the wind throughout its entire height and width the pressure upon all vertical surfaces thus exposed shall be taken as not less than 20 lb. per sq. ft. [There are wide variations in the wind-load requirements of building codes throughout the country.]

An exhaustive study of "Wind Bracing in Steel Buildings" has been made by a committee for the American Society of Civil Engineers and reported upon in the 1940 *Transactions* of that Society. One recommendation of that committee is as follows:

As a standard wind load for the United States and Canada, the Sub-Committee recommends a uniformly distributed force of 20 pounds per square foot for the first 300 feet above ground level, increased above this level by 2.5 pounds per square foot for each 100 feet of height, no omission of wind force being permitted for the lower parts of the building by reason of alleged shelter. Special wind-force specifications should be formulated locally for areas that are definitely known to be subject to hurricanes or tornadoes.

In order that a building may be secure against overturning, the Sub-Committee recommends that the factor of safety against uplift be not less than 1.5. In other words, the axial tension due to wind load in the critical column should not be more than two-thirds of the dead-load compression in the bottom story of the column, unless the columns are securely anchored to the foundations by anchors proportioned at the permissible stress applicable to members carrying wind only. Moreover, the foundation itself should be adequate for one and one-half times any uplift that may be imposed on it.

Many other phases of the question of wind forces and wind bracing, including the wind forces on sloping and arched roofs, are considered in this report.

Earthquake Shocks. The disastrous effects which earthquakes have had on buildings in many parts of the world is a matter of record. Practically no part of this country has been free from earthquakes during the rather brief period covered by records.[10] However, experience has shown that the probability of severe earthquakes in certain sections of the country is so great that definite provisions should be made for earthquake shocks.

Earthquakes produce accelerations in the ground surface which may be resolved into vertical and horizontal accelerations. Normally the vertical acceleration which would tend to increase or decrease, depending upon the momentary direction of the earthquake acceleration, the apparent weight of a building and its contents, is neglected. The horizontal effect of an earthquake at any floor is considered to be equal to the weight of the building and its contents above that floor multiplied by an assumed acceleration which is taken as a specified percentage of the acceleration due to gravity. If the earthquake acceleration is assumed to be 5 per cent of the acceleration, the horizontal force at any floor would be 5 per cent of the weight of the building and its contents above that floor. Actually the problem is not so simple as this would indicate, but building codes follow this procedure. Fortunately, well-

designed and well-constructed buildings, with the various parts securely tied together, will stand earthquake shocks of considerable magnitude without serious structural damage even though no special provision has been made for earthquakes.

In most parts of this country, building codes make no mention of earthquake shocks, but municipalities in California have adopted codes which require that buildings be designed to withstand horizontal acceleration varying from 2 per cent to 10 per cent of the acceleration due to gravity, distinction being made between buildings of different types of construction.[11] Allowable stresses are also increased when earthquake shocks are considered. A regulation applying to all public buildings in California is in effect.

The following recommendations for provisions to be incorporated in the codes applying in localities where such legislation is desirable are made in Appendix G of the "Building Code" recommended by the National Board of Fire Underwriters:[6]

1. *When Required.* Buildings more than one story high above a basement or cellar, and buildings or other structures exceeding 20 ft. in height except buildings of frame construction or unprotected metal construction, shall be designed and constructed to resist the effect of earthquake shocks in accordance with the requirements of this section.

2. *Forces To Be Resisted.* *a.* The forces to be resisted shall be assumed to be applied horizontally at each floor level at right angles to the side of the building from any direction.

b. Such forces shall be assumed at the following percentages of the weight of the building or structure above the plane of application: Five per cent when the foundations rest on rock or hardpan; 7½ per cent when they rest on soil the bearing capacity of which is not less than 2 tons per sq. ft., and 10 per cent when they rest on soil the bearing capacity of which is less than 2 tons per square foot.

c. The weight of the building or structure shall be taken to include the dead load and total live loads prescribed by this ordinance as a minimum or the live load for which the building or structure is designed when in excess of the prescribed minimum.

According to Jacob J. Creskoff,[12] who has given the problem considerable study:

It seems to be generally accepted that the aseismic design of a tall building is a dynamical problem. However, some engineers and architects, attracted by the relative simplicity of the statical theory and believing it safe, maintain that a building of moderate height can be considered a "simple" rigid structure, and may therefore be designed statically. . . . The fatal weakness of the statical method is that, although buildings designed statically are of necessity made arbitrarily strong and rigid to take care of unrepresented

factors so that safe designs are sometimes accidentally obtained, the final result is always in doubt.

The codes mentioned in preceding paragraphs follow the statical theory.

REFERENCES

1. BUREAU OF FOREIGN AND DOMESTIC COMMERCE, U. S. DEPARTMENT OF COMMERCE: "Construction Activity in the United States," 1915–1937. Prepared under direction of LOWELL J. CHAWNER.

2. *Survey of Current Business:* "The Construction Industry in 1939," Annual Review Number, February, 1940.

3. *Engineering News-Record:* Annual Construction Costs Issue.

4. CLARK, W. C., and J. L. KINGSTON: "The Skyscraper," American Institute of Steel Construction, 1930.

5. BUILDING CODE COMMITTEE, U. S. DEPARTMENT OF COMMERCE: "Recommended Practice for the Arrangement of Building Codes."

6. NATIONAL BOARD OF FIRE UNDERWRITERS: "Building Code," 5th Ed., Revised Reprint, 1934.

7. BUILDING CODE COMMITTEE, U. S. DEPARTMENT OF COMMERCE: "Recommended Minimum Requirements for Fire Resistance in Buildings."

8. NATIONAL BOARD OF FIRE UNDERWRITERS: "Building Codes, Their Scope and Aims."

9. BUILDING CODE COMMITTEE, U. S. DEPARTMENT OF COMMERCE: "Minimum Live Loads Allowable for Use in Design of Buildings," 1925.

10. FREEMAN, JOHN R.: "Earthquake Damage and Earthquake Insurance," McGraw-Hill Book Co., 1932.

11. Pacific Coast Building Officials Conference: "Uniform Building Code," 1940.

12. CRESKOFF, JACOB J.: "Earthquakes and Reinforced Concrete." *Journal of the American Concrete Institute,* Vol. 33, 1937.

CHAPTER II

BUILDING MATERIALS

ARTICLE 4. GENERAL DISCUSSION

The materials considered in this chapter are those which are used in many parts of a building. Other materials whose use is limited to one part of a building are considered in the appropriate chapters.

Masonry materials such as brick, stone, hollow clay tile, concrete blocks and tile, architectural terra cotta and cast stone are considered in Chapter IV, on Masonry Construction. Flooring materials such as clay tile, magnesite composition, asphalt mastic, and linoleum are considered in Chapter IX. Roofing materials are considered in Chapter X, glass in Chapter XIV, and painting materials in Chapter XVI.

To assist in the understanding of the methods of manufacture of building materials, some of the fundamental principles of chemistry will be explained in this article.

The Elements, Compounds, and Mixtures. All substances are made up of elements. An *element* may be defined as a substance which can not be separated by any known means into substances different from itself. There are about 90 known elements. If two or more substances are mixed together and can then be separated by mechanical means, a *mechanical mixture* is formed; but if they combine in definite proportions to form a homogeneous mass whose components can not be separated mechanically, a *chemical compound* is formed. *Alloys* and *solutions* are formed by mixing substances together to form other substances which are homogeneous and can not be separated into their components mechanically, but these substances need not be in absolutely definite proportions and therefore are not chemical compounds.

Atoms and Molecules. According to the atomic theory, an *atom* is the smallest particle of an element which can exist either alone or in combination with similar particles of the same or of a different element. The atoms of one element have the power of attracting atoms of other elements to form *compounds*. The combination of atoms forms *molecules* which are the smallest particles of a compound that can exist. Given elements always combine in definite proportions when they form the same substance. For instance, when hydrogen and oxygen combine to form water, they always unite in the proportions of 2 atoms of hydrogen to 1 atom of oxygen. The weight of an atom of oxygen is 16 times as great as the weight of an atom of hydrogen; therefore, by

weight, 2 units of hydrogen combine with 16 units of oxygen to form 18 units of water. The same elements may sometimes combine in different proportions to form different substances. For instance, 1 atom of carbon will combine with 1 atom of oxygen to form 1 molecule of carbon monoxide, and 1 atom of carbon will combine with 2 atoms of oxygen to form 1 molecule of carbon dioxide.

Chemical Symbols, Formulas, and Equations. For convenience, each element is designated by a *symbol*. The elements which compose practically all building materials and the symbols for these elements are:

Aluminum	Al	Nickel	Ni
Calcium	Ca	Nitrogen	N
Carbon	C	Oxygen	O
Chlorine	Cl	Phosphorus	P
Copper	Cu	Potassium	K
Hydrogen	H	Silicon	Si
Iron	Fe	Sulphur	S
Lead	Pb	Tin	Sn
Magnesium	Mg	Zinc	Zn
Manganese	Mn		

Compounds are designated by *formulas* formed by combining the symbols of the component elements. The number of atoms of each element in the molecule of the compound is indicated by a subscript figure. For instance, the formula for water is H_2O. This indicates that water is formed by a combination of hydrogen and oxygen in the proportions of 2 atoms of hydrogen to 1 atom of oxygen.

The changes which occur when elements or compounds combine are indicated by chemical *equations*. For instance, the equation for the chemical change which takes place when the elements hydrogen and oxygen combine to form the compound water is

$$2H + O = H_2O$$

A more complicated change takes place when the compound quicklime (CaO) absorbs the compound carbon dioxide (CO_2) from the air while setting to form the compound calcium carbonate. This is indicated by the equation

$$CaO + CO_2 = CaCO_3$$

One of the changes which takes place in a blast furnace in the manufacture of pig iron is the reaction of three molecules of carbon monoxide (CO) with one molecule of iron oxide (Fe_2O_3) to form three molecules of carbon dioxide (CO_2) and two molecules of iron (Fe) thus

$$3CO + Fe_2O_3 = 3CO_2 + 2Fe$$

In all equations the number of atoms of each element on one side must equal the number of atoms of that element on the other side; in other words, the equations must balance.

Many other details might be explained but enough has been given so that a general idea of the use of equations can be formed.

Acids, Bases, and Salts. Most compounds may be classed as acids, bases, or salts. *Acids* are compounds, containing hydrogen, which will react with the metallic oxides known as *bases,* to form neutral compounds called *salts.*

Some of the common acids are: hydrochloric (HCl), sulphuric (H_2SO_4), and nitric (HNO_3). Quicklime (CaO), magnesia (MgO), and potash (K_2O) are examples of bases. Common salt is sodium chloride ($NaCl$) and is formed by adding hydrochloric acid to the base soda thus:

$$Na_2O + 2HCl = H_2O + 2NaCl$$

Common Compounds. The chemical names and the chemical formulas for some of the more common compounds used in building construction are:

SUBSTANCE	CHEMICAL NAME	FORMULA
Alumina	Aluminum oxide	Al_2O_3
Carbonate of lime	Calcium carbonate	$CaCO_3$
Quicklime	Calcium oxide	CaO
Slaked lime	Calcium hydroxide	$Ca(OH)_2$
Sulphate of lime	Calcium sulphate	$CaSO_4$
Magnetite	Magnetite	Fe_3O_4
Hematite	Ferric oxide	Fe_2O_3
Litharge	Lead monoxide	PbO
Red lead	Red lead oxide	Pb_3O_4
White lead	Basic lead carbonate	$2PbCO_3 \cdot Pb(OH)_2$
Magnesia	Magnesium oxide	MgO
Magnesium carbonate	Magnesium carbonate	$MgCO_3$
Manganese dioxide	Manganese dioxide	MnO_2
Silica	Silicon dioxide	SiO_2
Sulphur dioxide	Sulphur dioxide	SO_2
Salt	Sodium chloride	$NaCl$
Zinc white	Zinc oxide	ZnO
Zinc sulphate	Zinc sulphate	$ZnSO_4 \cdot 7H_2O$
Muriatic acid	Hydrochloric acid	HCl
Nitric acid	Nitric acid	HNO_3
Sulphuric acid	Sulphuric acid	H_2SO_4
Vinegar	Acetic acid	$HC_2H_3O_2$
Carbonic acid gas	Carbon dioxide	CO_2
Water	Water	H_2O

ARTICLE 5. PIG IRON, CAST IRON, AND WROUGHT IRON

Pig Iron

Definition, Composition, and Uses. *Pig iron* may be defined as the product obtained by the reduction of iron ores in the blast furnace. It contains 91 to 94 per cent of iron; 3.75 to 4.50 per cent of carbon;

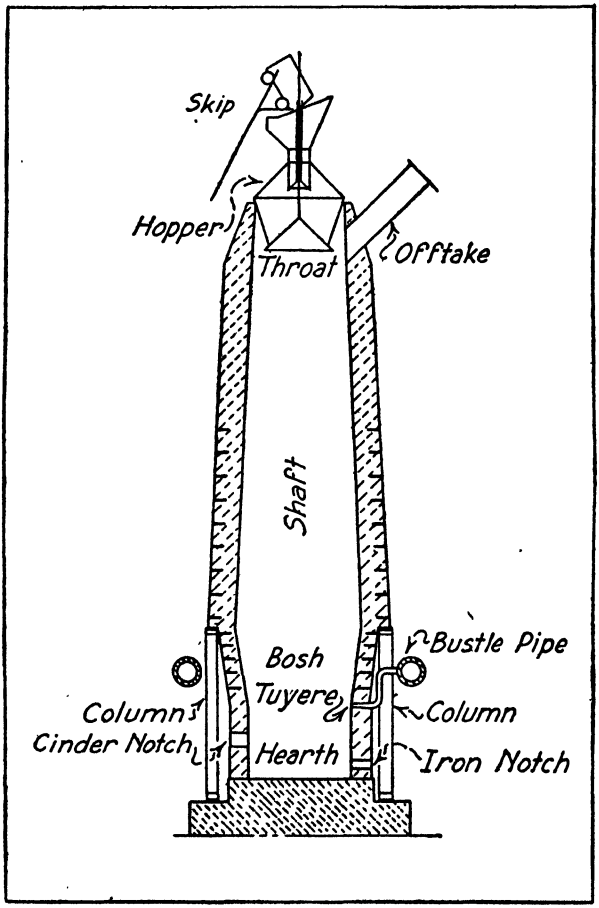


FIG. 6. Blast Furnace

0.25 to 3.50 per cent of silicon; 0.03 to 1.00 per cent of phosphorus; and less than 0.10 per cent of sulphur.[1] A vertical section through a blast furnace is shown in Fig. 6.

Pig iron may be used directly in making castings but its most important use is in the manufacture of cast iron, wrought iron, and steel where it may be used in a molten state direct from the blast furnace or in the

form of *pigs*, which are castings made from the pig iron as it is drawn from the furnace.

Raw Materials. The raw materials used in the manufacture of pig iron are: the iron ores which furnish the iron; the fuel which furnishes the heat and the reducing agent; the flux which provides a fusible slag which carries off ash of the fuel and some of the impurities of the ore; and the air which supplies the oxygen for the combustion of the fuel.

Iron ores of commercial importance may be divided into four classes: iron oxides, iron carbonates, iron silicates, and iron sulphides. Only the oxides are of importance in this country. The oxides of iron used in the manufacture of pig iron are:

Hematite, Fe_2O_3, containing about 70 per cent iron when pure;
Limonite, $Fe_2O_3 \cdot n.H_2O$, which is hydrated hematite containing about 60 per cent iron when pure;
Magnetite, Fe_3O_4, containing about 72 per cent iron when pure.

Impurities in the ore, such as sand and clay, are called the *gangue*.

The fuel has two functions in the manufacture of pig iron: the furnishing of the necessary heat and the supplying of the reducing agent to combine with the oxygen of the ore. The fuels used are coke, coal, and charcoal. On account of its porosity and resistance to crushing, coke is superior to coal and charcoal and is usually used. A small amount of charcoal iron is produced in this country; because of its purity it sells for a higher price than ordinary pig iron.

The functions of a *flux* are to make the impurities in the ore and fuel, such as silica and alumina, more easily fusible and to provide a fusible slag in which these and other impurities may be carried off. The flux used in the blast furnace is usually limestone, which, when pure, is calcium carbonate and has the chemical formula $CaCO_3$ although a considerable amount of magnesium carbonate ($MgCO_3$) is commonly present.

The Blast Furnace. The blast furnace is a structure 90 to 100 ft. in height, approximately cylindrical in shape, built of fire brick, inclosed more or less completely in a steel shell. The furnace is divided into three main parts: the *hearth*, or *crucible*, the *bosh*, and the *stack*, as shown diagrammatically in Fig. 6.

The hearth is provided with an *iron notch* and a *cinder notch* through which the iron and slag are periodically removed. Just below the bosh a ring of 10 to 16 *tuyeres* penetrate the lining. The air necessary for the process is blown through these tuyeres, which are all connected to the *bustle pipe* which encircles the furnace and which is in turn connected to the hot-blast stoves, which heat the air, and finally to the

blowing engines which provide the air at a pressure of from 15 to 30 lb. per square inch.

At the top of the furnace there is a device which permits the raw material to be charged into the furnace but prevents the escape of the gases. These gases are heated to a very high temperature and contain a large amount of carbon monoxide (CO) which is combustible. In the early days these gases were permitted to burn as they left the furnace, but now they are used in the hot-blast stoves, under steam boilers, and in internal-combustion engines. This results in a considerable saving in fuel. The larger furnaces of the present time have a capacity of 600 tons of pig iron per day.

Operation. A blast furnace is operated continuously by charging the *burden,* which consists of ore, fuel, and flux in proper proportions, in the top of the furnace and drawing off the slag and iron at the bottom, the slag being tapped at intervals of about 2 hours and the iron at intervals of about 5 hours. The iron may be used in the molten state in the manufacture of wrought iron or steel or may be cast into bars called *pigs* for subsequent use.

Chemical Changes. Air contains about one part of oxygen to four parts of nitrogen and other inert gases. The air enters the blast furnace through the tuyeres at a temperature of about 1000 deg. fahr. and a pressure of from 15 to 30 lb. per square inch. It immediately comes into contact with hot coke and the oxygen of the air combines with the carbon of the coke forming carbon dioxide (CO_2), thus:

$$C + O_2 = CO_2 \tag{1}$$

On account of the excess of carbon which exists, the carbon dioxide is reduced to carbon monoxide (CO) thus:

$$CO_2 + C = 2CO \tag{2}$$

The ore as it moves down through the furnace encounters this carbon monoxide, which is a powerful reducing agent, and the following reactions result, the first occurring near the top of the furnace at a temperature of approximately 600 deg. fahr., and the last, in the lower part of the stack at a temperature of about 1400 deg. fahr.:

$$2Fe_2O_3 + 8CO = 4Fe + 7CO_2 + C \tag{3}$$

$$3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2 \tag{4}$$

$$Fe_3O_4 + CO = 3FeO + CO_2 \tag{5}$$

$$FeO + CO = Fe + CO_2 \tag{6}$$

Reactions 1 and 3 produce most of the heat required by the other

reactions and heat to dry the raw materials, to decompose the limestone, to flux the impurities, and to melt the iron and slag. The temperatures in the furnace increase from about 500 deg. fahr. at the top to about 3600 deg. fahr. in the crucible.

Other changes occur but they are too confusing to consider here. However, it may be well to mention that the heated coke acts as a reducing agent in much the same manner as the carbon monoxide considered above.

The limestone in the charge breaks up into calcium oxide and carbon dioxide at about 1600 deg. fahr.; thus:

$$CaCO_3 = CaO + CO_2 \tag{7}$$

the CO_2 being reduced to CO when it encounters the hot coke. At about this same temperature the iron, which is in a spongy form, absorbs carbon from the coke. This lowers its melting point and it becomes fluid.

At the top of the bosh, the lime (CaO) combines with some of the gangue, a little unreduced iron oxide, and manganese oxide from the ore and forms slag which, with the molten iron, runs down through the coke to the hearth where the slag and the molten iron separate into two layers owing to the difference in their densities, the slag — being the lighter — remaining on top.

In the hearth, part of the oxides of manganese (Mn_3O_4), silicon (SiO_2), and phosphorus (P_2O_5) are reduced by the carbon of the coke, which extends through to the bottom of the furnace, and join the iron. The remainder of the oxides are not so acted upon, and are found in the slag. All of the phosphorus present in the charge will be found in the iron but the amounts of silicon and manganese in the pig iron will depend upon furnace conditions. Sulphur is introduced into the blast furnace mainly as an impurity in the coke in the form of iron sulphide. Some of this reacts with the lime forming calcium sulphide and joins the slag but the remainder is found in the iron, for iron sulphide is soluble in iron. Conditions which tend to decrease the amount of sulphur present in the iron also tend to increase the amount of silicon.

Cast Iron and Malleable Cast Iron

Production. Cast iron is manufactured by remelting pig iron and pouring it into molds to form castings of the desired shape when the metal solidifies in cooling. Scrap iron, consisting chiefly of discarded castings, is used with the pig iron because it is less expensive than pig iron. No chemical changes of importance take place during the process of remelting.

Molds and Patterns. The process of making castings is called *iron founding*. The molds are made of sand; the impressions in the sand are usually made by *wood patterns*. In *loam molding* no pattern is used, the impression being formed in the sand by hand or machine. Patterns must be slightly larger than the objects to be cast, to allow for the shrinkage of the metal in cooling. Vertical surfaces must be slightly tapered to facilitate the withdrawal of the pattern from the mold. This taper is called *draft*.

Gray and White Cast Iron. When molten cast iron solidifies, the carbon which is present remains combined with the iron as *carbide of iron* (Fe_3C) or may separate from the iron as *graphite*. White cast iron contains carbon chiefly in the combined state. It has a white metallic fracture and is very hard and brittle. Gray cast iron contains carbon chiefly in the form of graphite mechanically mixed with the iron but some carbon is present in the combined state. It has a gray, crystalline fracture and is not so hard and brittle as white cast iron. The graphite in cast iron is in the form of flakes which reduce its strength very materially. Slow cooling and the presence of silicon tend to increase the amount of graphite in cast iron whereas rapid cooling and the presence of manganese and sulphur tend to hold the carbon in the combined state. Cast iron increases in strength as the amount of combined carbon is increased up to about 1.2 per cent. Further increases cause a loss of strength. The hardness and brittleness increase as the amount of combined carbon is increased. In general, cast iron has a high compressive strength and a low tensile strength.

Chilled Castings. Chilled castings are produced by using molds with certain surfaces made of iron. The iron which comes in contact with these surfaces is therefore cooled suddenly and the carbon in the iron remains in a combined state (Fe_3C) for a certain depth, forming white cast iron which is very hard. The remainder of the iron cools naturally and forms gray cast iron which is not so hard but is less brittle. Surfaces of cast iron which are subject to wear are often chilled to increase their life.

Malleable Cast Iron. Castings made of white cast iron may be made malleable and ductile by subjecting them to an annealing process which converts the combined carbon into free carbon in a very finely divided state. The annealing may be accomplished by packing the castings in some inert material such as sand or clay and heating to a red heat which is maintained for several days, after which the castings are slowly cooled.

Better results may be secured by packing the castings in an oxidizing material such as iron oxide. The oxide draws the carbon from the cast-

ings to a depth of $\frac{1}{16}$ inch or more, forming a skin of soft iron on the castings in addition to converting the combined carbon in the body of the castings into free carbon.

White cast iron is used so that all the free carbon will be in the form of very minute particles evenly distributed throughout the castings and not in the form of large flakes which have such a weakening effect on gray cast iron.

Malleable castings are used for small articles such as builders' hardware. Malleable iron washers are quite extensively used in timber construction.

Wrought Iron

Manufacture. Wrought iron is made by melting pig iron in a reverberatory furnace, the hearth of which is lined with iron oxide, as shown diagrammatically in Fig. 7. The fuel usually used is soft coal. The carbon, silicon, manganese, phosphorus, and sulphur in the molten pig iron come in contact with the oxygen in the lining of the hearth and

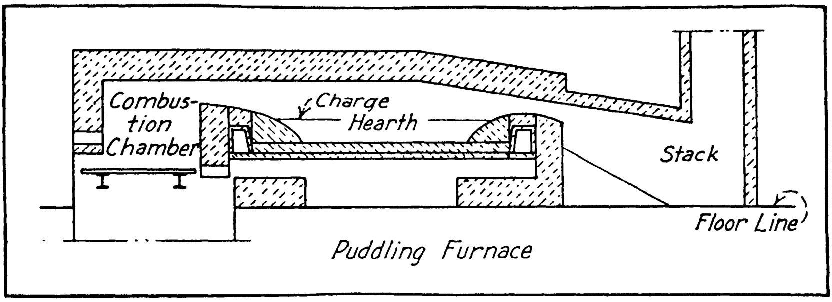


FIG. 7. Reverberatory Puddling Furnace

in the air and become oxidized forming a slag on top of the iron. As the iron becomes purified, its melting point is raised above the temperature of the furnace so that it assumes a pasty form. The iron in this condition is worked together in the hearth to form *puddle balls* which are removed from the furnace by hand. These balls contain a considerable amount of slag, most of which is expelled by squeezing, hammering, and finally rolling to form *muck bars.* These bars are piled, heated to a welding temperature, and rolled to form *merchant bars* which are the finished product.

Properties and Uses. Wrought iron is composed of very pure iron mechanically mixed with a small amount of slag. The rolling process has elongated the particles of iron and slag which existed in the puddle ball so that a fibrous structure is produced. The properties of wrought

iron correspond to those of pure iron which is tough, ductile, easily welded, and comparatively low in tensile and compressive strength. It is superior to ordinary steel in resisting corrosion. In building construction, wrought iron is used for pipe and for ornamental iron work.

ARTICLE 6. STEEL

Comparison of Steel with Other Ferrous Products. The various methods and processes for manufacturing steel have as their primary object the reduction of the amount of carbon present in pig iron, but the amount of phosphorus, sulphur, manganese, and silicon is also controlled.

Steel differs in physical properties from pig iron, and differs from cast iron by being ductile rather than brittle and by being malleable. It differs from malleable cast iron by being malleable without treatment subsequent to being cast. It differs from wrought iron chiefly by the process of manufacture, rather than by any great difference in physical properties.

Steel differs in chemical composition from pig iron, cast iron, and malleable cast iron chiefly by having a much lower percentage of carbon, but also by the smaller amounts of manganese, silicon, and phosphorus present. Low-carbon steel and wrought iron differ very little in chemical composition, but with wrought iron the iron itself contains a smaller percentage of impurities for the reason that a part of the impurities are in the slag which is mechanically mixed with iron.

Effect of Composition on Properties. The element which has the most pronounced effect on the physical properties of steel is carbon. The amount of carbon present in steel may vary from almost 0 to about 1½ per cent. Increasing the amount of carbon, increases the strength, hardness, and brittleness of steel but decreases the ductility. Steel may be classified according to carbon content approximately as follows:

	Carbon Content, Per Cent
Soft, mild, or low-carbon steel	Up to 0.30
Medium or medium-carbon steel	0.30 to 0.70
Hard or high-carbon steel	0.70 to 1.05

There is no distinct line of demarcation between the various grades so these limits are subject to considerable variation.

Silicon, in the amounts usually found in steel, has little effect on its properties, but when the amount present is as high as 0.3 or 0.4 per cent it increases the strength without a sacrifice in ductility.

Sulphur has little effect on the strength or ductility of steel, but it

makes steel brittle and liable to crack when worked at red heat. This is called *red shortness*. The maximum amount of sulphur permitted by specifications for structural steel is about 0.05 per cent.

Phosphorus causes steel to be brittle at ordinary temperatures, or *cold short*, and is therefore very objectionable. The maximum amount of phosphorus permitted by specifications for structural steel is about 0.06 per cent.

Manganese in amounts ordinarily present is beneficial to steel but its action is too complex to consider here.

Effect of Mechanical Working. The hammering, the pressing, and the rolling of steel while hot tend to eliminate flaws and, if the working is continued while the metal is cooling past a certain critical temperature, the steel will be fine grained, due to the breaking up of the crystals and to not permitting them to form again.

The cold-working of steel increases the strength and elastic limit but decreases the ductility.

Effect of Heat Treatment. Heating, annealing, and sudden cooling have very marked effects on the strength, ductility, and grain size of steel, but this subject is too complex for consideration here.

Processes of Manufacture. The principal processes used in manufacturing steel are: the cementation process and the crucible process, which produce steel by adding carbon to wrought iron; and the Bessemer process and open-hearth process, which produce steel by purifying pig iron. Only the last two processes are used in making structural steel; therefore only these processes will be considered here. The open-hearth process is rapidly replacing the Bessemer process.

Bessemer Process

The acid and the basic Bessemer processes are used in the manufacture of steel. The acid process will be considered first.

Plant. In the acid Bessemer process for making steel, molten pig iron is charged into a vessel called a converter, constructed as shown diagrammatically in Fig. 8*a*. This converter consists of a steel shell with a lining composed chiefly of silica and is provided with tuyeres in the bottom through which air may be forced. The converter is mounted on a horizontal axis on which it can be rotated. The capacity of a converter is about 15 tons of pig iron.

Operation. While being charged with molten pig iron, the converter is tipped, as shown in Fig. 8*b*. The blast is turned on and the converter is rotated to a vertical position, as shown in Fig. 8*a*. The pressure of the blast varies from 10 to 25 lb. per square inch. The blow is continued for about 10 minutes, during which time a flame issues from the mouth

of the converter. This flame is caused by the burning of the gases given off during the process. The operator judges from the appearance of the flame when the process is complete and pours the steel into a ladle by tipping the converter. From the ladle the steel is poured into ingot molds to form ingots.

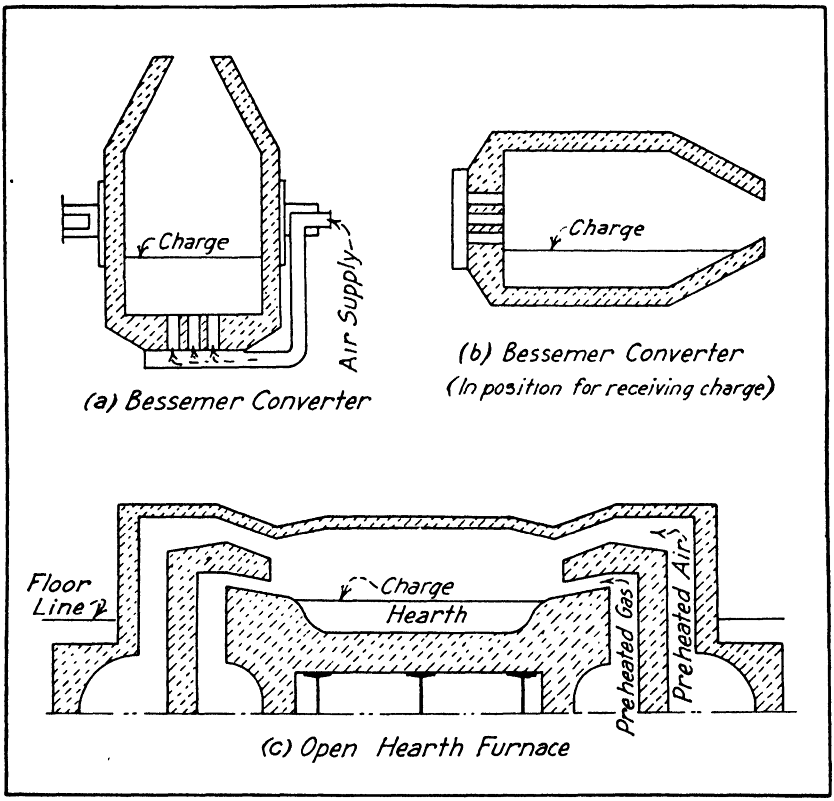


FIG. 8. Bessemer Converter and Open-Hearth Furnace

Removal of Impurities. The oxygen in the air blast combines with the silicon, manganese, and carbon in the pig iron, forming the oxides SiO_2; MnO; and CO. The oxides of silicon and manganese form a slag which separates from the iron, and the carbon monoxide, being a gas, passes out through the open end of the converter where it combines with oxygen from the air, forming carbon dioxide (CO_2). The phosphorus and sulphur present in the pig iron are not removed by this process, and the pig iron used must not contain large enough amounts of these materials to be objectionable in the steel. Since all of the phosphorus

which is present in the ore charged into the blast furnace joins the pig iron, it is evident that the only ores which can be used for acid Bessemer steel are those which do not contain enough phosphorus to injure the steel. Such ores are not plentiful in this country and so are expensive and hence place a limit on the use of the acid Bessemer process.

Sources of Heat. The melting point of the purified iron is higher than that of the pig iron, so if no heat were generated in the process the iron would not remain in a molten state. The heat required for the process is furnished primarily by the oxidation of the silicon, but the oxidation of the carbon and the manganese furnish some heat.

Recarburizing. During the process, all of the carbon is removed from the pig iron and some iron oxide is formed. The amount of carbon desired in the steel is introduced by adding a *recarburizer* to the molten metal while it is still in the converter, or after it has been poured out into the ladle. The recarburizer has other functions to perform: the deoxidation of the steel, the introduction of elements such as manganese to improve the quality of the steel, and the removal of the small amount of carbon monoxide gas which tends to remain in the steel and cause blow holes. The material used as a recarburizer is a special pig iron which is high in manganese and carbon.

The Basic Process. The process which has just been described is called the acid process because the slag formed is acid in character and requires a converter lining, which is also acid in character, to prevent chemical action between the lining and the slag. Phosphorus can be removed by the basic process where lime is charged into the converter to produce a slag which is basic in character. The phosphorus is the chief source of heat in the basic process, and ores, in order to be suitable for this process, must be high in phosphorus. The basic process is not used in this country largely because of the lack of suitable ores.

Advantages and Disadvantages. The chief advantages of the Bessemer process are its rapidity, the simplicity of the plant, and the saving in fuel. The disadvantages are the lack of suitable ores and the variability of the product, the process depending largely on the skill of the operator in judging the time required for the reactions by the appearance of flame issuing from the mouth of the converter. The use of Bessemer steel is rapidly declining in favor of open-hearth steel.

Open-Hearth Process

Plant. The open-hearth process for manufacturing steel is performed in an open-hearth furnace, as shown diagrammatically in Fig. 8c. There are two open-hearth processes, the acid and the basic. The basic process will be considered first.

The Basic Process. The furnace consists essentially of a hearth in the central portion and of two openings, called *ports*, at each end. The hearth is lined with calcined magnesite, with anhydrous tar as a binder. Under the action of heat the tar burns to coke and becomes hard and firm. The capacity of the furnaces in use varies from 50 to 100 tons.

Operation. In charging the furnace, pig iron, steel scrap, iron ore, and limestone are placed on the hearth through doors on one side of the furnace. The furnace is heated by introducing preheated gas through one port at one end of the furnace and preheated air through the other port at the same end. The gas and air ignite at the ports. The exhaust gases are drawn through both ports at the other end by natural draft. These gases pass through regenerators filled with checker brick and heat these brick to a high temperature. In about 20 minutes, valves are turned so that the direction of flow of the gases is reversed. The gas and air are preheated by passing through the regenerators which were heated by the exhaust gases. Regenerators are provided at each end of the furnace so that one set is always being heated by the exhaust gases while the other is heating the incoming gas and air. The direction of flow is changed at intervals of 15 or 20 minutes. The regenerators make it possible to heat the furnace to a temperature high enough to melt the charge in 4 or 5 hours. The process requires 6 to 12 hours to accomplish the removal of the impurities. Then the furnace is tapped through a tap hole and the molten steel is run into ladles.

Removal of Impurities. The oxygen in the iron ore of the charge is the oxidizing agent which combines with the silicon, manganese, and phosphorus present in the charge, forming the corresponding oxides which, with the lime of the charge, form the slag. The carbon present in the materials charged into the furnace is oxidized by the oxygen of the iron ore, forming carbon dioxide gas which leaves the furnace with the other exhaust gases. The elimination of sulphur is quite uncertain.

Sources of Heat. Some heat is supplied by the oxidation of the impurities but most of the heat is obtained from the combustion of the fuel which may be gas, fuel oil, or powdered coal.

Recarburizing. The process is always continued until the amount of carbon present is less than that desired in the finished steel. The additional carbon is supplied by adding ferromanganese with coal, charcoal, or coke to the metal in ladle.

The Acid Process. The process just described is the basic process because the slag formed is basic in character and requires a basic lining for the hearth in order to prevent any chemical action between the slag and the lining. Phosphorus can be removed by the basic process but not by the acid process; and since all of the ores in this country con-

tain phosphorus in objectionable amounts, the acid process has very little use.

The acid process differs from the basic in the following respects: the lining of the hearth is acid in character instead of basic; the charge must be low in phosphorus; and the recarburizing may be done in the furnace instead of in the ladle as in the basic process.

Advantages and Disadvantages. The chief advantage of the open-hearth process over the Bessemer process is the possibility of better control owing to the slowness of the process. The chief disadvantages are the time required and the additional fuel necessary, the heat in the Bessemer process being supplied entirely by the oxidation of the impurities in the charge. Open-hearth steel is generally specified for structural purposes. The use of Bessemer steel is rapidly declining.

Special Steels

Various alloying elements are introduced into steel to change the properties, such as increasing the strength, in some desired manner. Included in these elements are silicon, manganese, copper, nickel, chromium, tungsten, molybdenum, and vanadium. They may be introduced singly or two or more may be used.

A common steel used for decorative purposes, for sinks and counter-tops, and for other building purposes is *stainless steel*, which resists corrosion, takes a high polish, and is attractive in appearance. It is made by adding more than 18 per cent of chromium and 8 per cent nickel to steel.

Small amounts of copper, ranging from 0.15 to 0.30 per cent, introduced in steel increase its resistance to atmospheric corrosion without significant effect on its other properties.[1,2] *Copper-bearing steel* is extensively used for sheet-metal products.

ARTICLE 7. NON-FERROUS METALS AND ALLOYS

Copper

Ores. Copper is found in the native or pure state and in a great variety of ores of which the sulphides are the most common.

Extraction. The stages in the extraction of copper from sulphide ores are:

1. *Concentrating* the lean ores by crushing and passing through stamp mills and then through *jigs*, where the ore is shaken so that the heavier material containing the copper falls to the bottom and the lighter material rises to the top. This lighter material is washed away by a stream of water, leaving the concentrate containing a high percentage of copper, with considerable iron present as an impurity.

2. *Roasting* the sulphide ore by heating in an oxidizing atmosphere where a part of the iron sulphide ore is converted into the oxide by the burning out of the sulphide. The temperature is not high enough to melt the ore. The roasted ore contains chiefly copper sulphide, iron oxide, and siliceous gangue, although some copper oxide may be present.

3. *Smelting* in a blast furnace with coke as a fuel or in a reverberatory furnace similar to that used in the manufacture of wrought iron as described in Art. 5. Copper sulphide and iron sulphide settle to the bottom forming a *matte*; and the slag, containing the *gangue* or earthy materials and iron oxide, forms on top where it may be drawn off.

4. *Converting* the molten *matte*, containing the sulphides of copper and iron, in a converter similar to that used in the manufacture of Bessemer steel. Air is blown through the molten matte and provides oxygen which combines with the iron sulphide, forming a slag of iron oxide on top of the remaining copper sulphide. By continuing the process, the sulphur is burned out of the sulphides, forming sulphur dioxide which passes off as a gas and leaving an impure form of copper known as *blister copper.*

5. *Refining* the blister copper either in a reverberatory furnace or electrolytically. In *furnace-* or *fire-refining* the blister copper is melted in a reverberatory furnace; the slag which is formed is skimmed off; air is blown over the molten bath and oxidizes the impurities which either pass off as gas or form slag on top of the molten metal. Some of the copper is oxidized and must be reduced by adding charcoal and green branches of trees to the bath. Steam formed by the water in the green branches agitates the bath and the carbon from the charcoal, and the charred branches combines with the oxygen of the copper oxide, forming carbon monoxide which passes off as a gas, thus leaving fairly pure copper which is cast into ingots.

In the *electrolytic process* anodes of blister copper or fire-refined copper and cathodes of pure copper are placed in a copper sulphate bath. An electric current is passed through the bath and causes pure copper to be transferred from the blister copper anode to the pure copper cathode. The impurities, which often include the precious metals, are not soluble in copper sulphate and being of higher specific gravity fall to the bottom of the bath and are removed.

Fire-refined copper is not as pure as that obtained by the electrolytic process. The former is used for wires, tubes, and plates and for making brasses and bronzes. The latter is used primarily for electrical purposes which require the purer form.

Properties and Uses. The most important properties of copper are its electrical conductivity and its resistance to corrosion. Its strength

and ductility are greatly affected by the mechanical and heat treatment it receives. If heated to a red heat and cooled slowly it is brittle, but if cooled quickly it is malleable and ductile. It may be cast and welded and may be rolled or drawn when hot or cold. Cold-working increases its strength but decreases its ductility. When exposed to moist air, as when used for a roofing material, a thin coating of the green basic carbonate is formed. This protects the copper so that no further treatment is required.

Copper is used primarily for electrical purposes but it is also used extensively as a constituent of brasses and bronzes and for sheet-metal roofing and shingles, gutters, rain conductors, flashing, and pipe for plumbing. Copper wire is formed by drawing through dies. If it is cold-drawn, it produces what is called *hard-drawn wire* which is springy.

Zinc

The ores of zinc are the sulphide (ZnS) called *sphalerite, black jack,* or *zinc blende;* the carbonate ($ZnCO_3$) called *smithsonite* or *zinc spar;* the silicates ($Zn_2\ SiO_4\ H_2O$) called *calamine* and ($Zn_2\ SiO_4$) *willimite;* and franklinite, which is composed of the oxides of zinc, manganese, and iron. The most common source of zinc is zinc blende.

Extraction. The stages in the extraction of zinc from its ores are:

1. *Roasting* the ore to drive off the sulphur from sulphides and the carbon dioxide from the carbonates to form zinc oxide.

2. *Mixing* the oxide with nearly an equal amount of finely ground coal or coke and placing in fire-clay retorts.

3. *Heating* retorts to a white heat so that the coal or coke will form carbon monoxide which will combine with the oxygen of the zinc oxide forming carbon dioxide and zinc vapor.

4. *Condensing* the zinc vapor at a temperature above the melting point of zinc to form molten zinc which is poured into molds and allowed to cool forming *zinc spelter* which is the form commonly used. If the temperature at which the condensation is carried on is too low, *zinc dust* is formed. This can not be melted to form a solid mass and has a limited use in the powdered form.

Properties and Uses. Zinc has a fairly high resistance to corrosion. For this reason it is used as a roofing material in the form of sheet zinc. Exposure to the weather causes dull gray zinc carbonate to form on the surface. This protects the remainder of the metal.

If zinc is cooled suddenly from the molten state it is malleable but if cooled slowly it is hard and brittle. Commercial zinc is quite brittle but if heated to about 250 deg. fahr. it becomes malleable and ductile. It may then be drawn into wire or rolled into sheets which are ductile

and malleable when cool. Molten zinc shrinks very little in solidifying and casts well.

Zinc is extensively used as a protective coating for steel in the galvanizing and sherardizing processes. It is also used as one of the constituents in brass, nickel, silver, and other alloys and in making electric batteries.

Lead

Ores. The only important ore of lead is *galena* which is the sulphide (PbS) mixed with gangue.

Extraction. The stages in the extraction of lead from its ores are:

1. *Roasting* by charging crushed ore into a reverberatory furnace where it is heated at a low temperature in an oxidizing atmosphere. Part of the sulphur in the sulphide is oxidized forming lead oxide and sulphur dioxide gas and some lead sulphate is formed, thus:

$$PbS + 3O = PbO + SO_2$$
$$PbS + 4O = PbSO_4$$

2. *Smelting* the lead oxide, the lead sulphate, and the remaining lead sulphide in a blast furnace with limestone, coke, and some other materials to form lead and sulphur dioxide, thus:

$$PbS + 2PbO = 3Pb + SO_2$$
$$PbS + PbSO_4 = 2Pb + 2SO_2$$

The molten lead thus formed is drawn off and cast into ingots. This lead must usually be purified before it is ready for the market.

Properties and Uses. The important physical properties of lead are its resistance to corrosion, its plasticity, and its malleability.

Lead sheets are used to considerable extent for water-tight pans under the floors of shower baths and in similar positions. They are used to a limited extent for roofing, particularly for curved or irregular surfaces to which lead can be easily fitted by stretching and working. Lead has a high coefficient of expansion and is difficult to hold in place, particularly on pitched roofs.

A roofing known as *hard lead* is composed of lead and antimony. It is stronger and has a lower coefficient of expansion than ordinary lead and can be used on any slope.

Lead pipes are used in plumbing but not to the extent they were in former years. The pipe is formed by forcing the metal through dies by means of hydraulic presses. The term *plumber* is derived from the Latin word *plumbum* meaning lead.

Solder is an alloy of lead and tin.

Aluminum

Ores. Aluminum occurs very abundantly in nature in combination with oxygen, sodium, fluorine, and silicon. The chief source of aluminum is *bauxite,* which is hydrated oxide of aluminum and iron with some silicon. The most extensive occurrence of aluminum is as the oxide alumina (Al_2O_3) which is the principal constituent of clay. No process has yet been devised to obtain aluminum from clay in commercial quantities.

Extraction. The stages in the extraction of aluminum from bauxite are:

1. *Roasting* bauxite to drive off the water.
2. *Grinding* roasted bauxite and heating under pressure with a solution of sodium hydrate forming sodium aluminate.
3. *Precipitating* aluminum hydroxide by heating sodium aluminate solution with aluminum hydroxide or with carbon dioxide.
4. *Separating* aluminum hydroxide with filtering and dehydrating by heating to form alumina (Al_2O_3).
5. *Extracting* aluminum from alumina by the electrolytic decomposition of alumina in a molten bath of cryolite which is the fluoride of alumina and sodium.

In the last-named process the containing vessel is lined with carbon in the form of graphite or coke which forms the cathode. Carbon rods suspended in the bath form the anode to which the oxygen goes. The cryolite is melted by the heat generated by the passage of the electric current across a gap which exists between the anodes and the cathodes. When the cryolite bath becomes molten, alumina is thrown on the bath and as it melts it is broken up into molten aluminum, which settles on the cathode, and oxygen, which goes to the anode with which it combines, forming carbon monoxide which escapes as a gas. The molten aluminum is tapped off as it accumulates. The heat for the process is supplied by the electric current.

Properties and Uses. Aluminum has a low electrical resistance which makes it valuable for transmission lines and other electrical uses. It is a good heat conductor and is non-corrosive and so is useful in either the cast or spun form for cooking utensils. It has many special uses on account of its lightness; its weight is only about one-third that of iron but it is usually alloyed with other metals which increase its strength. It is very malleable, quite ductile, and is strong in proportion to its weight. It may be drawn into wire and rolled into structural shapes and very thin sheets and shaped in many other ways.

Tin

Ores. The principal source of tin is the black oxide (SnO_2), known as *cassiterite* or *tinstone*. Tin is the only important metal not found in the United States.

Extraction. The stages in the extraction of tin from its ores are:

1. *Concentrating* the ore by stamping and washing to remove the lighter materials.

2. *Roasting* in a reverberatory furnace to oxidize the sulphur and arsenic which exist as impurities. These oxides pass off as gases.

3. *Smelting* in reverberatory or blast furnaces. The oxygen of the tin oxide combines with carbon to form carbon dioxide, the carbon being mixed directly with the ore in the furnace, or the oxygen combines with carbon monoxide derived from the partial combustion of coal used as a source of heat. The molten tin accumulates and is drawn off. This crude or raw tin contains copper, iron, arsenic, sulphur, and other impurities.

4. *Refining* by liquation and boiling. The ingots of crude tin are placed in a reverberatory furnace and as the temperature is gradually increased the tin melts and is removed leaving the unfused impurities. The molten tin thus obtained is still further purified by boiling while bundles of green twigs are held submerged in the molten tin. The steam given off by the green twigs develops violent boiling which causes the impurities to become oxidized by coming in contact with the air. These oxides form a scum on the surface. This scum is removed and the tin is cast into ingots. Some of the impurities are heavier than the tin and do not pass into the scum but settle toward the bottom. For this reason the tin which comes from the top of the vessel is purer than that which comes from the bottom. The former is called *refined tin* and the latter *common tin.* The common tin is often liquefied and boiled again.

Properties and Uses. Tin is very malleable and may be rolled into very thin sheets which are called *tinfoil.* It is very resistant to corrosion. Its principal use is in coating sheet iron or steel to form *tin plate* for use as a roof covering. Tin plate used for roofing does not have a coating of pure tin but of an alloy of 25 per cent tin and 75 per cent lead. This is known as *terne plate* and is much less expensive than *bright* tin plate which is coated with pure tin.

Tin is used in making bronzes and other alloys.

Alloys

The Brasses. The *brasses* are alloys of copper and zinc. The most useful brass alloys range in composition from 60 per cent copper and 40

per cent zinc to 90 per cent copper and 10 per cent zinc. Standard brass contains 2 parts of copper to 1 part of zinc and is the most commonly used of all the brasses. Those carrying a large amount of copper are copper red in color and those with a small amount of copper are a silvery white.

Brass may be shaped by casting, hammering, stamping, rolling into sheets, or drawing into wire or tubes.

Muntz metal contains 60 per cent copper and 40 per cent zinc.

The addition of even small amounts of tin to brass greatly increases the resistance to corrosion.

The Bronzes. The *bronzes* are alloys of copper and tin ranging in composition from 95 per cent copper and 5 per cent tin to 75 per cent copper and 25 per cent tin. The chief effect of tin on copper is to increase its hardness.

Gun metal contains 90 per cent copper and 10 per cent tin. It is the strongest of the bronzes. *Bell metal* contains 80 per cent copper and 20 per cent tin. It is hard and is used for making bells. *Speculum metal* contains 2 parts copper and 1 part tin. It is a hard white metal which will take a polish and is used for making mirrors.

Phosphor bronze is a copper-tin alloy to which a small amount of phosphorus has been added as a deoxidizer to eliminate copper oxide. This results in a very marked improvement in the strength and quality of the bronze. It is highly resistant to corrosion.

Manganese bronze is really a brass for it contains a large amount of zinc and little or no tin. The manganese acts as a deoxidizer and does not appear in the resultant alloy as it has been oxidized and removed in the flux. The addition of manganese greatly improves the strength of the alloy. Manganese bronze is an excellent material for castings and is very resistant to corrosion.

Monel Metal. An important alloy of nickel and copper is *Monel metal,* which is about two-thirds nickel, somewhat less than one-third copper, with small amounts of iron, manganese, carbon, and silicon. It is resistant to corrosion, takes an attractive finish, and is easily worked. Monel metal is used for counter tops and sinks in buildings.

ARTICLE 8. WOOD

Definitions. The terms wood, lumber, and timber are often used synonymously but, as these terms are used in the building industry, there is a distinction between them. *Wood* is the hard fibrous substance which forms the major part of the stem and branches of trees. *Lumber* is wood which is the product of the saw or planing mill not manufactured further than sawing, resawing, and passing lengthwise

through a standard planing machine, crosscutting to length, and working.[5] *Timber* is lumber 5 in. or larger in least dimension.[5]

The term *millwork* is applied to the wood building materials manufactured in planing mills and millwork plants and includes such products as doors, window frames, shutters, porch work, interior trim, stairways, mantels, panel work, and moldings but not flooring, ceiling, and siding.[6]

Classification of Trees. Timber for construction purposes is furnished by two classes of trees: the *needle-leaved conifers* such as the pine, fir, and spruce, and the *broad-leaved trees* such as the maple, oak, and poplar. The woods furnished by the conifers are commonly classed as *softwoods* and those furnished by the broad-leaved trees as *hardwoods,* although poplar is as soft as pine and some of the softwoods are as hard as the harder hardwoods.

Manner of Growth. The conifers and broad-leaved trees grow by adding a layer of wood to all parts of the tree each year. This layer shows in the cross-section as a new ring surrounding the old wood and under the bark. The rings thus formed are known as *annual rings.*

Structure. The cross-section of a tree consists of the annual rings surrounding the *pith* at the center of the section and surrounded by the *bark.* The pith varies in diameter from $\frac{1}{20}$ in. in some kinds of wood to nearly $\frac{1}{4}$ in. in others.

The annual rings near the outside of the section form the *sapwood* and are lighter in color than those near the center which form the *heartwood.* The sapwood is active and assists in the life processes of the tree by storing up starch and conducting sap. The heartwood is dead, its only function being to contribute to the strength of the tree.

Each annual ring is made up of an inner portion which is relatively soft and light-colored and an outer portion which is harder and darker in color. The inner portion is formed early in the growing season and is known as *spring wood* whereas the outer portion is formed later and is known as *summer wood.* In some woods there is a distinct line of demarkation between the spring wood and summer wood, but in others the spring wood merges gradually into the summer wood.

Wood is composed primarily of long thin cells or fibers closed at the ends with their length parallel to the length of the tree. In addition to these cells there are other groups of cells running radially and forming the *medullary* or *pith rays.* In the conifers the sap is conducted through the cells by passing through the walls, but in the hardwoods the sap passes through cells with open ends set one above another forming continuous tubes called *pores* or *vessels.* In some of the conifers, such as pine and spruce, there are intercellular passages called *resin ducts* which

store and conduct resin. They occur horizontally, in the medullary rays, as well as vertically. The functions of the medullary rays are to store food and to provide for the passage of sap between the bark and the sapwood.

Though similar in many respects, the conifers and broad-leaved trees are very different in the structure of their wood. The structure of the wood of the conifers is simple and regular with a uniform type of cell or fiber. The wood of the broad-leaved trees is quite complex in structure with many different types of cells or fibers and a very irregular arrangement.

Chemical Composition. Dry wood, by weight, is one-half carbon and one-half oxygen and hydrogen with about 1 per cent of nitrogen and 1 per cent of earthy materials. When wood is burned, those constituents which were derived from the air return to the air and those which were derived from the soil return to the soil in the form of ashes. There is little variation in the chemical composition of the various kinds of wood. However, there are great differences in the structures and these are largely responsible for the differing physical properties.[7] The chemical elements which have been mentioned form the cellulose and lignin of which wood is composed.

According to the " Wood Handbook ":[6]

Wood is composed of about 60 per cent cellulose, 28 per cent lignin, and minor quantities of other materials. Cellulose is a colorless material insoluble in ordinary solvents, such as water, alcohol, and benzine, and in dilute acids and alkalies. It forms the framework of the cell wall.

Lignin is also insoluble in most ordinary solvents but more or less soluble in dilute alkalies. It constitutes the cementing material that binds the cells together and is mixed with cellulose in the cell walls. By dissolving the lignin with suitable reagents the cells may be separated, as in chemical paper-making processes.

Cellulose and lignin are responsible for many of the general properties of wood, such as its hygroscopicity, resistance to corrosion by salt water and dilute acids, and susceptibility to decay. These two major constituents are found in about the same proportions in all species, but in addition there are small quantities of other materials in wood, some of which give certain species or groups of species clearly distinctive characteristics. Color, odor, and natural resistance to decay, for example, come from materials other than the cellulose or lignin.

Use Classification. Softwood lumber is divided into three general classes according to use.

1. *Factory and shop lumber* is intended to be cut up for use in further manufacture.

2. *Yard lumber* is that which is intended for general purposes. It includes lumber which is less than 5 in. thick. This lumber, about three-quarters of all lumber produced, is carried in retail lumber yards.

3. *Structural lumber* is intended for use where working stresses are of importance. It includes lumber that is 2 or more in. thick and 4 or more in. wide.

Size Classification. The American Lumber Standards[1] for softwood lumber classify lumber according to size as follows:

Yard Lumber:
- *Strips* are less than 2 in. thick and less than 8 in. wide.
- *Boards* are less than 2 in. thick and 8 or more in. wide.
- *Dimension* includes all yard lumber except boards, strips and timbers, i.e., yard lumber from 2 in. to, but not including, 5 in. thick and any width.
- *Timbers* are 5 in. or more in least dimension.

Structural Lumber:
- *Dimension* (joists and planks) is from 2 in. to, but not including, 5 in. thick and 4 or more in. wide.
- *Timbers* are 5 in. or more in least dimension and are subdivided into:
  - *Beams* and *stringers* which are of rectangular cross-sections 5 or more in. thick and 8 or more in. wide.
  - *Posts* and *timbers* which are square or approximately square in cross-sections and 5 in. by 5 in. and larger.

Manufacturing Classification. Lumber is classified according to the extent to which it is manufactured as follows:

- *Rough lumber* is undressed as it comes from the saw.
- *Surfaced lumber* is dressed by running it through a planer. It may be surfaced on one side (S1S), two sides (S2S), one edge (S1E), two edges (S2E), or on a combination of sides and edges such as (S1S1E), (S2S1E), (S1S2E), or (S4S).
- *Worked lumber* has been run through a matching machine, sticker, or molder. It may be:
  - *Matched lumber*, which has a close tongue-and-groove joint at the edges or, in the case of *end-matched lumber*, at the ends also.
  - *Shiplapped lumber*, which has a close-rabbeted or lapped joint at the edges.
  - *Patterned lumber*, which is shaped to a patterned or molded form.

Hardwood lumber does not have a definite use classification corresponding to that for softwood lumber.

Grading. The designation of the quality of a manufactured piece of wood is called the *grade*. Lumber may be stamped by a mark which

designates its grade and the mill where it was produced. Such lumber is said to be *grade-marked.* The reasons for grading are given in Circular 64 of the U. S. Department of Agriculture entitled, " How Lumber is Graded," by H. S. Betts, as follows:

The boards cut in a sawmill from logs of various kinds vary widely in quality. Some boards are very knotty, others have a few knots, and still others are clear. Some contain checks or splits and others have bark on the edges or are somewhat decayed in places. The clear boards are more valuable for most purposes than those with knots, so it becomes necessary to separate the lumber as it comes from the mill into classes or grades. The lumber in these grades varies in quality from practically clear boards in the highest grade to lumber in the lowest grade containing so many knots, checks, and other defects that it is unfit for anything except perhaps temporary construction or for cutting up to obtain small, clear pieces, the defective parts being discarded.

The use to which lumber is to be put determines the number, size, and position of the defects it may contain and still be satisfactory. In siding, for example, a reasonable number of knots on the edges which are covered when the siding is in place may evidently be allowed. In flooring some knots and other defects on the under side are allowable, since they will not show when the flooring is in use. Sheathing and subflooring may have a considerable number of defects, since both kinds of lumber are entirely covered by finishing material. Covered lumber, such as sheathing, should, of course, be free from decay, even if it does not show, as the decay is quite likely to spread rapidly. Door panels are an example of very high grade lumber that should be clear on both sides.

The location of defects in a piece of lumber determines the length and width of clear pieces that can be cut from it and the waste that will occur when the cuttings are made. Furniture requires comparatively short, wide pieces of clear lumber, while rails for porches and stairs require long, narrow, clear lengths. Lumber from which a large proportion of furniture stock should be cut might yield very little rail stock.

The condition of defects may also influence the grade of a piece of lumber. Tight knots in certain grades of siding or ceiling may be allowed, whereas loose knots likely to drop out would be objectionable.

The American Lumber Standards for softwood lumber[5] by the National Bureau of Standards serve as a basis for the grading rules that each regional softwood lumber manufacturers' association adopts and applies to its own species of lumber. These various associations' grading rules are those by which softwood lumber is graded. Corresponding grading rules have been adopted by various hardwood manufacturers' associations, but each set of grading rules applies to specific products such as maple flooring, oak flooring, dimension stock, trim, etc.

Basis of Grading. *Yard lumber* is graded on the basis of the intended use of the particular grade. Grading is applied to each piece with reference to its size and length when graded, without consideration of further manufacture. The grading rules prescribe the number, extent, and limitations of characteristics or defects permitted in the poorest pieces admissible in each grade, but a grade shall be representative and not comprise only low-line pieces.

Factory and shop lumber is graded on the basis of the percentage of the area which will produce a limited number of cuttings of a specified, or of a given minimum, size and quality.

Structural lumber is graded on the basis of the strength of the piece and the use of the entire piece.

Hardwood-Lumber Grading. The standard rules for the grading of hardwood lumber are those of the National Hardwood Manufacturers' Association. The basis of this grading is the amount of clear usable lumber in a piece. The standard grades are: firsts, seconds, selects, No. 1 common, No. 2 common. The extremes in quality may be illustrated by the difference between firsts and No. 2 common. The former must have a minimum width of 6 in. and requires that $91\frac{2}{3}$ per cent of the surface measure of a piece can be cut into clear face material. The latter must be cut into clear face material. The number of pieces into which a piece can be cut to give the required percentage of clear material depends upon the grade and upon the size of the piece. For example, a piece with 14 sq. ft. of surface measure can be cut into only 2 pieces with a minimum size of 4 in. by 5 ft., or 3 in. by 7 ft. if the piece is to be classed as firsts; but a piece of No. 2 common of this size can be cut into 7 pieces with a minimum size of 3 in. by 2 ft. There are other requirements which are not mentioned here.

Special grading rules are used for hardwood flooring, interior trim, and dimension stock.

Softwood Lumber Grading. The grade standards included in the American Lumber Standards for Softwood Lumber are used as the basis for this discussion.

Yard lumber is divided into two general grades, i.e., select and common. Select lumber is divided into Grades A, B, C, and D, while common lumber is divided into Grades 1, 2, 3, 4, and 5. Select timber is graded on the basis of appearance and its suitability for natural and paint finishes whereas common lumber is graded on the basis of its general utility for construction purposes. The various grades may be arranged diagrammatically as follows:

BASIC GRADE CLASSIFICATIONS FOR SOFTWOOD YARD LUMBER

Total products of a typical log arranged in series according to quality as determined by appearance and use.

- SELECT
  Lumber of good appearance and finishing qualities.
  - Suitable for natural finishes.
    - *Grade A.* Practically clear.
    - *Grade B.* Of high quality — generally clear.
  - Suitable for paint finishes.
    - *Grade C.* Adapted to high-quality paint finishes.
    - *Grade D.* Intermediate between higher finishing grades and common grades, and partaking somewhat of the nature of both.
- COMMON
  Lumber not of finishing quality, but which is suitable for general utility and construction purposes.
  - Suitable for use without waste.
    - *No. 1.* Sound and tight knotted. May be considered watertight.
    - *No. 2.* Less restricted in quality than No. 1, but of the same general character.
  - Permitting some waste.
    - *No. 3.* Prevailing grade characteristics larger than in No. 2.
    - *No. 4.* Low quality.
    - *No. 5.* Lowest recognized grade, but must be usable.

Factory and shop lumber are divided into grades appropriate to its use but, since the builder is concerned with the manufactured product itself and not with the grading of the lumber from which the product is made, no further consideration will be given to the grading of this class of lumber.

Structural lumber has not been divided into grades which have received general recognition but there has been considerable development in the direction of grading lumber for structural purposes on the basis of strength or allowable working stresses. Building codes commonly include working stresses based on the species of wood, without recognizing the effect of the variation in quality within each species. These variations in quality may have a more pronounced effect than the differences in species. In any system of grading which is to determine working stresses, the type of defects, their size, number, and location must be taken into account and the effect of the density of the wood must be given consideration.

The American Society for Testing Materials has adopted a specification for "Structural Wood Joist and Plank, Beams and Stringers, and Posts and Timbers,"[9] which gives the requirements of various species of wood to qualify for given working stresses. The following properties are considered: density in terms of the number of annual rings per inch of radius; slope of grain with reference to the axis of the piece; size and position of knots; size and position of shakes, checks, and splits.

Various lumber associations have recommended working stresses to be used for each grade of structural lumber which they produce.[6]

Defects in Lumber. In the grading of lumber it is necessary to classify and define the defects and blemishes which occur in the lumber. The commonly recognized defects and blemishes occurring in softwood yard lumber as given by the American Lumber Standards are:

A *bark pocket* is a patch of bark partially or wholly inclosed in the wood. In size it is classified the same as pitch pockets.

Bird's-eye is a small central spot with the wood fibers arranged around it in the form of an ellipse so as to give the appearance of an eye. Bird's-eye, unless unsound or hollow, shall not be considered a defect.

A *check* is a lengthwise separation of the wood, which occurs usually across the rings of annual growth.

A *cross break* is a separation of the wood cells across the grain, such as may be due to tension resulting from unequal shrinkage or mechanical stresses.

Cross-grained wood is that in which the cells or fibers do not run parallel with the axis, or sides of a piece.

Decay is a disintegration of the wood substance due to the action of wood-destroying fungi. The words *dote* and *rot* mean the same as decay.

A *gum spot* or *streak* is an accumulation of gumlike substance occurring as a small patch or streak in a piece. It may occur in conjunction with a bird peck, or other injury to the growing wood. In size they are classified the same as pitch pockets or pitch streaks.

Imperfect manufacture includes all defects or blemishes which are produced in manufacturing, such as chipped grain, loosened grain, raised grain, torn grain, skips in dressing, hit and miss, variation in sawing, miscut lumber, machine burn, machine gouge, mismatching, and insufficient tongue or groove.

A *knot* is a branch or limb embedded in the tree which has been cut through in the process of lumber manufacture. Knots are classified according to size, form, quality, and occurrence. The average of the maximum and minimum diameters shall be used in measuring the size of knots, unless otherwise stated.

Pitch is a poorly defined accumulation of resin in the wood cells in a more or less irregular patch.

A *pitch pocket* is a well-defined opening between rings of annual growth, usually containing, or which has contained, more or less pitch, either solid or liquid. Bark also may be present in the pocket.

A *pitch seam* is a shake or check which is filled with pitch.

A *pitch streak* is a well-defined accumulation of pitch in a more or less regular streak.

Pith is the small soft core occurring in the structural center of a log. The wood immediately surrounding the pith often contains small checks, shakes, or numerous pin knots, and is discolored; any such combination of defects and blemishes is known as *heart center*.

A *pith fleck* is a narrow streak resembling pith, usually brownish, up to several inches in length, on the surface of a piece resulting from burrowing of larvae in the growing tissue of the tree.

A *shake* is a lengthwise separation of the wood, which occurs usually between and parallel to the rings of annual growth.

A *split* is a lengthwise separation of the wood, due to the tearing apart of the wood cells.

Stain is a discoloration, occurring on or in lumber, of any color other than the natural color of the piece on which it appears.

Wane is bark, or the lack of wood or bark, for any cause, on the edge or corner of a piece.

Warp is any variation from a true or plane surface. It includes bow, crook, cup, or any combination thereof.

The standards include several subdivisions under each of the defects and blemishes which have been quoted.

In the grading of the hardwoods the defects which have been adopted as standard differ somewhat from those recognized for the softwoods. Each of the following counts as a standard defect, the grade of a piece being determined largely by the number of standard defects it contains:

1. One knot $1\frac{1}{4}$ in. in diameter.
2. Two knots $\frac{5}{8}$ in. in diameter or their equivalent. Knots of $2\frac{1}{2}$ in. in diameter count as 2 standard defects; those $2\frac{3}{4}$ in. in diameter as 3 standard defects, and those 5 in. in diameter as 4 standard defects.
3. One split diverging from parallel to the edges not more than 1 in. to a foot in length and not longer in inches than the surface in feet.
4. Wane not more than 1 in. wide and extending not more than one-sixth the length of the piece or its equivalent at one or both ends. (Wane is bevel or bark on the edge of a board and is due to incomplete edging of a board wider at one end than at the other.)
5. Worm, grub, knot, and rafting pin holes which do not exceed in damage or extent that of one knot $1\frac{1}{4}$ in. in diameter.
6. Equivalent defects. Heart center or pith and any other imperfections not listed as standard defects which do not damage the piece more than is done by allowable standard defects, are considered standard defects.

Plain- and Quarter-Sawed Lumber. Boards which are sawed from the logs with their face tangent to the annual rings are called *plain-sawed* or *flat-sawed* while those which are sawed in a perpendicular direction are called *quarter-sawed* or *edge-grain.*

Boards in which the annual rings or grain are neither tangent nor perpendicular to the sides are classed as quarter-sawed if the grain makes an angle greater than 45 deg. with the side of the board. If this angle is less than 45 deg. the boards are classed as plain-sawed. Quarter-sawed lumber shrinks and warps less than plain-sawed lumber and wears better. The exposed grains of wood are different when quarter-sawed than when plain-sawed. In some cases more attractive

effects are secured in quarter-sawed boards but in others the plain-sawed boards have the advantage. Quarter-sawed lumber is less plentiful than plain-sawed lumber and is more expensive.

Units of Measure. The principal unit of measure for lumber is the *board foot,* which is the quantity of lumber contained in, or derived from, by drying, planing, or working, or by any combination of these means, a piece of rough green lumber 1 in. thick, 12 in. wide, and 1 ft. long, or its equivalent in thicker, wider, narrower or longer lumber.[5] Lumber less than 1 in. thick is considered as 1 in. thick.

This method of measurement is called board measure and is abbreviated b.m. The common unit is 1000 board feet, designated as M. For example, if a lot of lumber contains 25,000 board feet it is designated as 25 M.b.m.

Moldings are measured by the lineal foot and lath and shingles by the number of pieces of a specified size.

Size Standards. The thicknesses and widths of yard lumber depend upon whether the lumber is green or dry and whether it is rough, as it comes from the saw, or dressed or surfaced by planing. The sizes by which this lumber is designated are called *nominal* sizes. These are equal to the rough-green sizes. The thickness of 1 in. dressed and surfaced yard lumber is $\frac{25}{32}$ in. For thicknesses of from 2 in. up to 7 in., $\frac{3}{8}$ in. is deducted from the nominal size to obtain the actual size, and above 7 in., $\frac{1}{2}$ in. is deducted. For widths from 2 in. up to 4 in., $\frac{3}{8}$ in. is deducted and above 4 in., $\frac{1}{2}$ in. is deducted. The rough-dry sizes are between the nominal and the dressed sizes.

Hardwood lumber is cut oversize so that it will be full size when dry. When surfaced on one side the thickness is $\frac{1}{8}$ in. less than the rough size, and when surfaced on two sides it is $\frac{3}{16}$ in. less than the rough size.

The standard lengths for softwood lumber vary by 2-ft. increments from 4 ft. up, the most common lengths being 12, 14, and 16 ft. A few odd lengths as 9, 11, 15, and 17 ft. are considered as standard for specified sizes. The standard lengths of hardwood lumber vary by increments of 1 ft. from 4 to 16 ft., but not over 15 per cent of the odd lengths is permitted by grading rules.

Seasoning. The *seasoning* of timber is simply the natural drying out due to exposure to the air. This drying-out process may be hastened by subjecting the timber to high temperatures in a kiln. This is called *kiln drying.* The principal effects of seasoning and kiln drying on timber are: reduction in weight; decrease in the amount of shrinking, checking, and warping after the timber is placed; increase in resistance to decay; and increase in strength.

Decay. The decay of timber is caused by low forms of plant life called *fungi* which feed on the cell walls and destroy them. In order to

develop, these fungi require warmth, air, and moisture. At low temperatures the fungi are dormant but are not destroyed. However they are killed by very high temperatures. Timber which remains under water will last indefinitely because the air which fungi require is excluded. Pieces of timber have lasted for thousands of years under water. If moisture is not present, wood will not decay. Even in *dry rot* moisture is present. It may be caused by sealing the surface of a timber with paint or embedding the timber in masonry in such a way that the moisture present in the timber can not escape and is therefore available for the development of fungi.

Insect Damage. Various boring insects attack timber and may cause considerable damage. Among these are *bark beetles,* which may damage wood by tunneling under the bark when the bark is left; *ambrosia beetles, roundhead borers,* which get into freshly cut timber; *powderpost beetles,* which attack freshly cut and seasoned hardwood by burrowing holes about $\frac{1}{16}$ in. in diameter through the wood; and *termites* or *white ants,* which are the most destructive of all and will be given further consideration. Most of the insect damage in wood construction is caused by termites which are light-colored, resemble ants in appearance, and like ants live in colonies and thus are commonly called white ants.

Two types of termites, the subterranean and the drywood, are found in this country. The *subterranean termites* live in the soil but leave the soil in order to attack trees and wood structures. To live, termites of this type must have access to moisture from the ground. Therefore they build shelter tubes from the ground to the spots where they are working. They bore holes along the grain on the interior of the wood members, leaving only the shell. A piece may appear to be in good condition but actually be on the verge of failure. The most effective means of control is to prevent the passage of the termites from the soil to the wood. This may be done by using concrete foundations reinforced so that they will not open where cracks form or else by using cement mortar in brick and stone masonry, taking care to fill all the joints solidly so that termites can not work their way through the joints. *Termite shields* of sheet copper or other non-corrosive metal should be placed between the top of the foundation walls and the wood plates or sills which are placed on them, as shown in Fig. 9. These should extend 2 in. over the edges of the wall and be bent down at an angle of 45 deg. This projection prevents the termites from building their shelter tubes from the foundation walls to the wood plates or sills. Extreme care should be used to remove all scraps of lumber from the building site. Wood treated with preservative by a process which penetrates

to the interior will resist termites but, since termites attack timber from the interior, surface coatings and sprays are ineffective. Subterranean termites are prevalent in nearly all parts of this country.

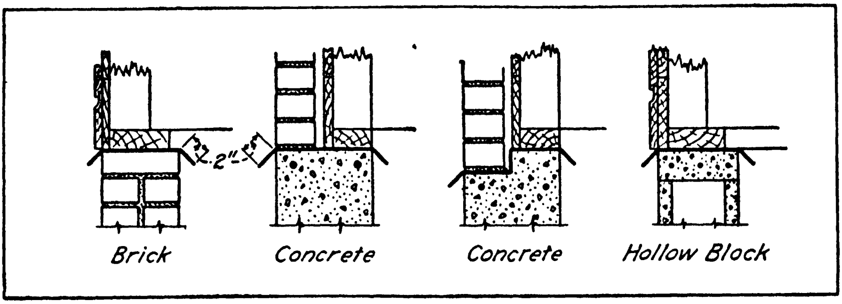


FIG. 9. Termite Shields.

Drywood termites attack wood directly and do not maintain contact with the ground. They are confined to the extreme southern parts of this country and are not such a serious menace as the subterranean termites. All structures in this country constructed wholly or partially of wood, except those of temporary character, should be protected against subterranean termites.

Marine Borers. Wood located in salt water, such as timber piles for marine structures, may be attacked by marine wood borers such as the *teredo* or *shipworm* and the *limnoria* or *wood louse.* Various methods of protecting wood against these borers have been devised, including impregnating with creosote but, since marine structures are not considered in this treatise, no further attention will be given to the subject.

Wood Preservation. The proper seasoning of timber is the simplest way to prevent decay but, when timber is used where moisture is present, seasoning naturally loses its effectiveness. Under these conditions the best method for checking decay is to introduce some substances into the timber which will poison the fungi. The substances commonly used for this purpose are zinc chloride and creosote. Zinc chloride is made by dissolving zinc in hydrochloric acid. Creosote is obtained from the distillation of coal tar. Zinc chloride is soluble in water and is suitable for use only where it will not be leached out by the action of water and when the method of application is such as to secure considerable penetration of the zinc chloride into the timber. Creosote does not suffer from these handicaps.

Creosote may be applied with a brush or spray but this method is not very effective for the coating is thin and it is difficult to fill all the cracks.

The advantage of this method is the low cost. Another simple method consists of dipping the timber in a tank of hot creosote. This method is more effective than brushing or spraying, but only a slight penetration of the creosote into the wood is secured.

In the *open-tank process* the timber to be treated is first placed in a tank of hot creosote and then in a tank of cooler creosote. While the timber is in the first tank, the air contained in the timber expands and some air is forced out. When the timber is placed in the second tank the air contracts and draws the creosote into the wood, thus securing a deeper penetration than is obtained by dipping in hot creosote alone.

Various processes are used to secure a deeper penetration of the preservative into the timber by pressure. These processes require extensive equipment and are expensive but their use is justified where the most effective treatment is required, as in piling. These processes use cylinders as large as 8 ft. in diameter and 150 ft. long. The material to be treated is loaded on cars and run into a cylinder, the ends of which are then closed by tight doors. In one process, the first step is to exhaust some air from the cylinder in order to draw the air and moisture from the timber. Creosote is then introduced into the tank and is forced into the cells of the wood by pressure. The treatment is completed by drawing off the creosote and removing the timber after the excess creosote has been permitted to drip off. This process leaves the cells, to the depth which the creosote has penetrated, full of creosote. It is known as the *full-cell process*.

In another process the creosote is first forced into the timber by pressure and then the creosote, which is in the cells, is removed by creating a vacuum. Only the creosote in the cell walls remains. This is known as the *empty-cell process* and is therefore less expensive than the full-cell process.

When zinc chloride is used, the full-cell process is adopted.

Fire-Retardant Treatments. The flaming characteristics of wood may be reduced by impregnation with water-borne chemicals such as ammonium phosphates or sulphate, borax, boric acid, or zinc chloride. They may also be reduced by oil-base or water-base paints in which fire-retarding chemicals have been incorporated, or by thick coatings whose effectiveness depends chiefly on their heat insulating properties. These are fire-retarding and not fireproofing treatments.[26]

Kinds of Wood, Their Properties and Uses. The more common woods used in building construction, their properties and other characteristics, their principal uses, the names by which they are known, and the regions in which they are produced are summarized in the accompanying tables. More detailed information is given in references 6 and 7 at the end of this chapter.

Broad Classification of Woods According to Characteristics and Properties

(Prepared Chiefly from Data in Selection of Lumber, U. S. Department of Agriculture, Farmers' Bulletin 1756)

Kinds of Wood	Working and Behavior Characteristics										Strength Properties				Surface Characteristics of Common Grades						Suitability for Various Uses															
	Hardness	Weight, dry	Freedom from shrinkage	Freedom from warping	Ease of working	Paint holding	Nail holding	Decay resistance, heartwood	Proportion of heartwood	Amount of figure	Bending strength	Stiffness	Strength as a post	Toughness	Number of knots	Size of knots	Number of pitch defects	Size of pitch defects	Number of other defects	Size of other defects	Exterior trim	Interior trim, natural finish	Interior trim, paint finish	Framing	Wall sheathing	Sub-floors	Roof boards	Siding	Lath	Shingles	Sash	Doors	Millwork, general	Flooring (only vertical grain for B)	Plywood	Veneer
Beech	A	A	C	C	C	—	A	C	B	B	A	A	B	A	B	B	None		A	A	—	B	B	b	—	b	—	—	—	—	—	—	A	—	—	—
Birch	A	A	C	B	C	—	A	C	C	B	A	A	B	A	C	B	None		B	B	—	A	A	b	—	b	—	—	—	—	—	—	A	—	—	H
Cedar, northern white	C	C	A	A	A	A	C	A	A	C	C	C	C	C	A	C	None		C	C	A	—	—	—	A	—	—	A	—	A	—	—	—	—	—	—
southern white	C	C	A	A	A	A	—	A	A	C	C	C	C	C	—	—	None		—	—	A	—	—	—	A	—	—	A	—	A	—	—	—	—	—	—
western red	C	C	A	A	A	A	C	A	A	B	C	C	B	C	C	A	None		C	C	A	—	—	—	A	—	—	A	—	A	H	—	—	—	—	—
eastern red	A	A	A	A	B	—	—	A	B	B	B	C	A	B	A	C	None		C	C	Lining cedar closets (H)					—	—	—	—	—	—	—	—	—	—	—
Cherry	A	B	B	A	C	—	—	—	B	B	A	A	A	B	C	B	None		—	—	—	A	A	—	—	—	—	—	—	—	—	—	—	—	—	—
Chestnut	B	B	B	A	B	—	B	A	A	A	C	C	C	B	C	A	None		A	B	—	A	B	b	A	b	—	—	—	—	—	H	W	H	—	—
Cypress, southern	B	B	B	B	B	A	B	A	B	A	B	B	B	B	C	B	None		B	B	A	B	B	a	—	—	—	A	B	A	A	—	—	B	—	—
Douglas fir	B	B	B	B	C	C	B	B	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	A	B	A	A	C	B	—	B	W	—	B	W	—
Fir, white	C	C	B	B	B	B	C	C	C	B	B	B	B	B	B	B	None		B	A	B	—	B	B	A	B	B	A	—	—	—	—	W	—	—	—
Gum, red	B	B	C	C	B	—	B	B	B	B	B	B	B	B	C	B	None		C	C	—	B	B	c	—	—	—	—	—	—	—	H	—	—	—	W
Hemlock, eastern	B	B	B	B	B	B	B	C	B	B	B	B	B	B	B	B	None		A	A	B	—	B	B	A	B	B	—	B	—	—	—	—	—	—	—
western	B	B	B	B	B	B	B	C	B	B	B	A	B	B	B	B	None		B	B	B	B	B	B	A	B	B	B	B	—	W	W	W	B	—	—
Larch, western	A	A	B	B	C	C	A	B	A	A	A	A	A	B	A	C	C	C	A	C	B	B	B	A	B	A	A	C	B	—	B	W	—	B	—	—
Maple, hard	A	A	C	B	C	—	A	C	C	B	A	A	A	A	B	B	None		B	B	—	B	B	b	—	b	—	—	—	—	—	—	W	A	—	H
Oak, red	A	A	C	B	C	—	A	C	B	A	A	A	B	A	C	A	None		B	B	—	A	B	b	—	b	—	—	—	—	—	—	—	A	—	—
white	A	A	C	B	C	—	A	A	B	A	A	A	B	A	C	A	None		B	B	—	A	B	b	—	b	—	—	—	—	—	—	—	A	—	—
Pine, ponderosa	C	B	B	A	A	B	B	—	C	C	C	C	C	C	B	B	B	B	B	B	B	—	A	b	A	B	B	B	A	—	A	W	W	—	—	—
southern yellow	A	A	B	B	C	C	A	B	C	A	A	A	A	B	C	A	A	A	B	B	B	B	B	A	B	A	A	C	B	H	B	—	—	B	—	—
northern white	C	C	A	A	A	A	B	—	B	C	C	C	C	C	A	C	C	C	B	B	A	—	A	b	A	b	—	A	A	—	A	—	W	—	—	—
western white	C	B	B	A	A	A	B	—	B	C	B	B	B	B	A	C	C	C	A	C	A	—	A	b	A	b	—	A	A	—	A	—	W	—	—	—
sugar	C	C	A	A	A	A	—	—	B	C	C	C	C	C	A	B	C	C	B	C	A	—	A	b	A	b	—	A	A	—	A	—	W	—	—	—
Poplar, yellow	C	B	B	A	A	—	B	C	B	B	B	B	C	C	C	B	None		C	C	A	—	A	b	A	—	—	B	A	—	H	H	H	—	—	—
Redwood	B	B	A	A	B	A	B	A	A	B	B	B	A	B	C	A	None		C	B	A	B	B	a	A	—	—	A	—	A	A	W	—	B	—	—
Spruce, eastern	C	B	B	A	B	B	B	C	C	B	B	B	B	B	A	C	C	C	B	B	B	—	B	B	A	B	B	B	A	—	—	—	W	—	—	—
Sitka	C	B	B	A	B	B	—	C	C	B	B	A	B	B	B	B	C	B	B	B	B	—	B	B	A	B	B	B	A	—	W	W	—	W	—	—
Walnut	A	A	B	A	B	—	—	A	B	B	A	A	A	A	C	B	None		C	C	—	A	A	—	—	—	—	—	—	—	—	—	—	A	—	W

A. Includes woods that are relatively high in the specific property or characteristic listed or which combine in a high degree the usual requirements for use.
B. Includes woods that are intermediate in the specific property or characteristic listed or which combine in a good degree the usual requirements for use.
C. Includes woods that are relatively low in the specific property or characteristic listed or which combine in a fair degree the usual requirements for use.
a, b, and c have the same meanings as A, B, and C except that the woods are not used extensively because of their adaptability to more exacting uses or because they are difficult to work.
W. Data obtained from "Wood Handbook."[6]
H. Data obtained from "Wood Construction" by Dudley F. Holtman.

PRINCIPAL BUILDING WOODS AND REGIONS OF GROWTH
(Compiled from "Wood Handbook" by U. S. Forest Products Laboratory)[6]

Kinds of Wood	Other Names	Principal Producing Regions
Beech	Red beech (heartwood), white beech (sapwood)	Eastern states except Florida, Pennsylvania, New York, Michigan, Indiana, Ohio, West Virginia
Birch	Red birch (heartwood), white birch (sapwood)	Northeastern states, lake states, Appalachian Mountains.
Cedar, northern white	Swamp cedar, white cedar, cedar	Lake states, northeastern states
southern white	Swamp cedar, white cedar, juniper	Eastern states near coast
western red	Red cedar, cedar, western cedar	North Pacific coast and inland from Washington to Montana
eastern red	Red cedar, cedar, juniper, pencil cedar, aromatic red cedar	
Cherry	Black cherry	Maine to eastern North Dakota and southward to central Florida and central Texas
Chestnut		Southern New England and Appalachians (Mostly killed by blight)
Cypress, southern	Red cypress (coast type), yellow or white cypress (inland type), tidewater red cypress, black cypress	Low swamp lands along southeastern coast and up the Mississippi valley to Missouri
Douglas fir	Red fir, Oregon fir, Douglas spruce, yellow fir, Oregon pine	Costal region of Washington, Oregon, and California, Montana, Idaho, inland Washington and Oregon
Fir, white	Colorado white fir	Idaho, California
Gum, red		Swamp and bottom lands of South
Hemlock, eastern	Hemlock, hemlock spruce, spruce pine, northern hemlock	Lake states and eastern mountains
western	Hemlock, hemlock spruce, Pacific hemlock, west coast hemlock	Pacific coast from Alaska to California

PRINCIPAL BUILDING WOODS AND REGIONS OF GROWTH

(Compiled from "Wood Handbook" by U. S. Forest Products Laboratory)[6]

Kinds of Wood	Other Names	Principal Producing Regions
Larch, western	Tamarack, larch	Montana, Idaho, Washington, Oregon
Maple, hard	Sugar maple, rock maple, black maple, sweet maple, white maple	Lake states, Northeast, Appalachians
soft	Silver maple, silverleaf maple, river maple, white maple	Eastern states
Oak, Red		Mississippi valley and South
white		Mississippi valley and South
Pine, ponderosa	Western yellow pine, western pine, western soft pine	Washington to North Dakota, Rocky Mountains, Pacific coast
southern yellow	Longleaf pine, shortleaf pine, southern pine, yellow pine, pitch pine	Atlantic and Gulf states, West Virginia, Kentucky, Missouri
northern white	White pine, cork pine, soft pine, northern pine, eastern white pine	Lake states, Northeast, Appalachians
western white	Idaho white pine, white pine, soft pine	Idaho, Washington, Montana
sugar	Big pine	California and southern Oregon
Poplar, yellow	Poplar, whitewood*	Eastern states, especially Appalachians
Redwood	Sequoia, coast redwood	Along coast of southern Oregon and northern California
Spruce, eastern	Red, white, and black spruce	Lake states, New England, and Appalachians
Sitka	Spruce, tideland spruce, western spruce, yellow spruce, silver spruce	Along coast from Alaska to northern California
Walnut	Black walnut	Missouri, Iowa, Ohio, Kentucky, Tennessee

* Holtman, *op. cit.* For complete information see reference 13.

ARTICLE 9. CEMENTING MATERIALS AND MORTARS

Gypsum Plasters

Raw Material. The basic material in all gypsum plaster is the mineral gypsum which occurs in three forms, *gypsum rock, gypsum earth* or *gypsite,* and *gypsum sand. Alabaster* is a pure form of gypsum.

When pure, gypsum is composed of one molecule of sulphate of lime and two molecules of water as indicated by the chemical formula $CaSO_4 + 2H_2O$. Gypsum is rarely found in a pure state but contains clay, limestone, iron oxide, and other impurities. Pure gypsum is a soft, white mineral.

Classification. Gypsum plasters are divided into four classes:

1. Plaster of Paris.
2. Cement, hard-wall, or patent plaster.
3. Flooring plaster.
4. Hard-finish plaster.

Changes in Manufacture and Setting. When gypsum is heated to temperatures between 212 deg. fahr. and 400 deg. fahr. it loses three-fourths the combined water as indicated by the equation:

$$(CaSO_4 + 2H_2O) + \text{Heat} = (CaSO_4 + \tfrac{1}{2}H_2O) + 1\tfrac{1}{2}H_2O$$

the one and one-half molecules of water being driven off as steam. The remaining product is *plaster of Paris* if pure gypsum is used in the process, and *cement plaster,* or *hard-wall plaster* if certain impurities are present or are added, these impurities causing the product to set more slowly than the rapid setting plaster of Paris. For a discussion of the various kinds of cement plaster see Art. 75.

If gypsum is heated above 400 deg. fahr. practically all the combined water is driven off as indicated by the formula:

$$(CaSO_4 + 2H_2O) + \text{Heat} = (CaSO_4) + 2H_2O$$

forming *dead-burned, hard-burned,* or *anhydrous* plaster. If pure gypsum is used the resultant product is known as *flooring plaster* but, if certain substances such as alum or borax have been added, *hard-finish plaster* is produced. *Keene's cement* is one variety of hard-finish plaster.

The setting of gypsum plasters is due to the recombination of the dehydrated lime sulphate, $CaSO_4$, or the partially dehydrated lime sulphate $(CaSO_4 + \tfrac{1}{2}H_2O)$ with water to form the original hydrated

sulphate ($CaSO_4 + 2H_2O$). The necessary water is added when the plasters are used.

Methods of Manufacture. Plaster of Paris and cement plaster are made by calcining or burning gypsum in large kettles or in rotary kilns. If kettles are used the gypsum is finely ground before burning, but for the rotary kilns the gypsum is crushed to a size of about 1 inch, the final pulverizing being accomplished after burning.

Flooring plaster is made by calcining pure gypsum in lump form in vertical kilns. After calcination the plaster is finely pulverized. The most common form of hard-finish plaster is Keene's cement. This material is formed by calcining lump gypsum, immersing in a 10 per cent alum solution, recalcining, and finally pulverizing to produce the finished product.

The time of set of cements or hard-wall plasters is regulated to suit the convenience of the workmen who are to use them. Ordinarily the setting must be delayed and therefore a *retarder* consisting of such materials as glue, sawdust, or blood, is added. If the time required for setting is too great, an *accelerator,* such as common salt, is used. Accelerators are not required in plasters for building purposes. The working qualities and sand-carrying capacity of cement or hard-wall plaster are improved by adding clay or hydrated lime by the manufacturers and their cohesiveness is increased by the addition of cattle hair or wood fiber. For use in localities where good sand is not available, plaster mixed with the proper amount of sand for use in plastering may be obtained from some manufacturers.

Uses. Plaster of Paris is used for ornamental castings, but on account of the rapidity with which it sets it is not suitable for use in a wall plaster or for mortar.

Cement or hard-wall plaster is very extensively used as a wall plaster for buildings but it will not withstand weathering action and is therefore not suitable for exterior use. Also blocks for use in fireproofing steel members and in constructing partitions, floors, and roofs of buildings are made with cement plaster. It is also used in the manufacture of plaster board, which consists of a core of plaster, with a covering of cardboard, pressed into sheets ¼ in. and ⅜ in. thick. Floor and roof slabs of skeleton steel construction are sometimes constructed of cement plaster and an aggregate reinforced with steel in a manner similar to reinforced concrete.

Flooring plaster is used to form the surface of floors. About 12 hours after the material has been placed, it is pounded with wooden mallets and smoothed with trowels to form a hard, durable surface. Flooring plaster is extensively used in Germany but is not used in this country.

Hard-finish plasters are employed as wall plasters when a waterproof and unusually hard surface is desired. *Keene's cement* is the best known of these plasters. *Parian cement* is another form.

For a discussion of the use of gypsum plasters see Art. 75.

Gypsum mortar for plastering is made by mixing cement plaster with from 1 to 3 parts sand, depending on conditions. The wood-fibered plaster may be used without sand or may be mixed with equal parts of sand. Gypsum mortar is always used for laying gypsum partition blocks, a 1 to 3 mixture being the most common.

Quicklime

Definition. *Quicklime* is the product resulting from the burning of limestone at a temperature sufficiently high to drive off the carbon dioxide.

Raw Materials. Pure quicklime is calcium oxide (CaO) and is obtained from pure limestone ($CaCO_3$), but commercial quicklime contains varying amounts of magnesium oxide (MgO) resulting from the presence of magnesium carbonate ($MgCO_3$) in the raw material. The chemical formula for the raw material used in lime manufacture is

$$x\,CaCO_3 + y\,MgCO_3$$

x and y being variables. Impurities such as silica, alumina, and iron are always present.

Classification and Grades. Quicklime is divided into four classes depending on the relative amounts of calcium oxide and magnesium oxide present: *high-calcium,* containing 90 per cent or over of calcium oxide; *calcium,* containing 75 to 90 per cent of calcium oxide; *magnesian,* containing between 25 and 40 per cent of magnesium oxide; *high-magnesian* or *dolomitic,* containing a high percentage of magnesium oxide. Common practice recognizes the division of quicklime into only two classes: *calcium limes* and *magnesian limes.*

Quicklime is divided into two grades: *selected,* which is a well-burned lime free from ashes, core, clinker, and other foreign material; and *run-of-kiln,* which is well-burned lime without selection.

Hydrated lime is furnished in two classes according to plasticity. *Masons' hydrated lime* has lower plasticity than finishing hydrated lime and is used for mortar and for the scratch and brown coats of plaster. *Finishing hydrated lime* has high plasticity and is used for the finish coat of plaster in addition to the uses made of masons' hydrated lime.

Manufacture. Quicklime is made by burning limestone in kilns at a temperature sufficient to drive off the carbon dioxide. If pure limestone

is used the process may be shown by the following formula:

$$CaCO_3 + \text{Heat} = CaO + CO_2$$

Calcium oxide (CaO) is a white solid and carbon dioxide (CO_2) is a gas. If magnesium carbonate is present a corresponding reaction occurs leaving magnesium oxide and driving off carbon dioxide gas.

The fuel used in the process is coal.

Slaking. In preparing lime mortar, quicklime is mixed with water forming calcium hydroxide, $Ca(OH)_2$. This is a fine white powder but an excess of water is always used, forming a paste called lime paste or *lime putty*. The chemical change which occurs in slaking pure quicklime is shown by the formula:

$$CaO + H_2O = Ca(OH)_2$$

A corresponding reaction occurs when magnesium oxide is present. The form of lime known as *hydrated lime* is simply the hydroxide formed by adding water to quicklime at the place of manufacture instead of on the job. While this change is occurring a considerable amount of heat is generated and a marked increase in volume occurs.

The calcium limes slake more rapidly than the magnesium limes and give off a greater amount of heat. For quick-slaking limes, the lime should be added to the water and when escaping steam appears the lime should be hoed and enough water added to stop the steaming. For medium-slaking and slow-slaking lime, add the water to the lime. Care must be taken to avoid cooling slow-slaking lime and in cold weather it may be necessary to heat the water. There is little danger that too much water will be added to the quick-slaking calcium limes but an excess of water may cause magnesium lime to be "drowned." If too little water is added to either calcium or magnesium limes they may be "burned." In either burning or drowning, a part of the lime is spoiled, for it will not harden and the paste is not as viscous and plastic as it should be.

Tests by the National Lime Association indicate that 4.5 to 8.5 cu. ft. of putty can be made from an 180-lb. barrel of quicklime containing 3.1 cu. ft., the quantity depending upon the kind of lime and the skill used in slaking.

Slaked lime should be allowed to age for 2 weeks before it is used for plastering but 24 hours may be sufficient if the lime is to be used for masons' mortar.

In making putty or paste from hydrated lime, the lime is sifted slowly into the water, the mixture being stirred constantly. The putty is allowed to age or soak at least 24 hours. The ageing process increases

the workability and sand-carrying capacity of the putty. Since hydrated lime has been slaked before shipping, the increase in volume while the putty is being made is small. A sack of hydrated lime weighing 50 lb. and containing 1 cu. ft. will make about 1.1 cu. ft. of lime putty.

Setting. In setting, the excess water is evaporated and the calcium hydroxide combines with carbon dioxide from the air to form calcium carbonate as shown by the formula:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$

A corresponding reaction occurs when magnesium hydroxide is present. The absorption of carbon dioxide occurs very slowly and in heavy masonry walls the setting may never occur.

The term *air-slaked* is often applied to quicklime which has become slaked by absorbing moisture from the atmosphere; but the process does not stop when this change has occurred, for the hydroxide thus formed absorbs carbon dioxide forming calcium carbonate, which has lost its cementing properties. To protect quicklime from air-slaking it is stored in barrels. Ground lime does not air-slake as readily as lump lime because the outer layer air-slakes and protects the remainder. It can therefore be shipped in bags.

Forms of Lime. The following definitions for various forms of lime which are manufactured have been adopted by the American Society for Testing Materials:

Quicklime is a calcined material, the major part of which is calcium oxide or calcium oxide in natural association with a lesser amount of magnesium oxide, capable of slacking in water.

Hydrated lime is a dry powder obtained by treating quicklime with water enough to satisfy its chemical affinity for water under the conditions of its hydration. It consists essentially of calcium hydroxide or a mixture of calcium hydroxide and magnesium oxide and magnesium hydroxide.

Lump lime is quicklime as it comes from the kilns.

Pulverized lime is quicklime which will pass a fine sieve of specified size, usually ¼ in.

Uses. Lime putty mixed with 2 or 3 parts sand by volume to form a mortar is used in building masonry walls and for plastering walls and ceilings. For a discussion of the use of lime in plastering, see Art. 75. Hydrated lime is furnished in 100-lb. cloth sacks and 50-lb. paper sacks, and lump lime in 180- and 280-lb. barrels.

Portland Cement

Definition. Portland cement is the product obtained by finely pulverizing the clinker produced by calcining to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.*

Raw Materials. The materials necessary in the manufacture of portland cement are lime, silica, and alumina. These materials are obtained by mixing an impure limestone, containing considerable clay, with pure limestone; by mixing limestone and clay or shale; or by mixing limestone and blast-furnace slag. They must be mixed in the proper proportions as determined by chemical analysis.

Manufacture. The steps in the manufacture are as follows:

1. Crushing the raw materials.
2. Drying the raw materials.
3. Grinding the raw materials.
4. Proportioning the raw materials.
5. Pulverizing the raw materials.
6. Burning to form clinkers.
7. Cooling the clinkers.
8. Adding the retarder to control the time of set.
9. Pulverizing the clinker to produce cement.
10. Seasoning of the cement.

The strength of concrete increases with the fineness of grinding of the cement. Specifications require that not more than 22 per cent of the cement be retained on a sieve having 200 meshes per inch.

The chemical changes which occur in the manufacture of portland cement are too complex to be considered here. The principal compounds formed, arranged in order of the proportions present, are

Tricalcium silicate	$3CaO \cdot SiO_2$
Dicalcium silicate	$2CaO \cdot SiO_2$
Tricalcium aluminate	$3CaO \cdot Al_2O_3$
Tetracalcium aluminum ferrite	$4CaO \cdot Al_2O_3 \cdot F_2O_3$

In addition to these are the following:

Calcium sulphate	$CaSO_4$
Free calcium oxide	CaO
Magnesium oxide	MgO

* Specifications of the American Society for Testing Materials, 1936. **Definition** in 1939 specifications is less descriptive.

There are several special types of portland cement which are used to accomplish special results. The two of these which are more commonly used are *high early-strength cement* and *low-heat cement*. They are manufactured by the same process and from the same materials as standard portland cement but they differ in the proportions of the ingredients used and vary in fineness of grinding. As the name implies, high early-strength cement attains strength more quickly in the early stages and may be used where it is desired to place the concrete into service quickly. Low-heat cement generates less heat in setting and acquires strength slowly. It is desirable for use in massive structures where the heat is retained in the concrete for long periods. The use of this type of cement results in lower temperatures, smaller volume changes, and less cracking in such structures than would be experienced if standard cement were used. Both these special cements produce concrete which ultimately acquires about the same strength as that made with standard cement.

Setting and Hardening. When water is added to portland cement a paste is formed. This paste soon loses its plasticity and begins to harden owing to complicated chemical changes which are started when the water is added. The process of setting is divided into two stages by specifications, i.e., *initial set* and *final set*. The progress of the setting is measured by the penetration of weighted needles constructed according to standard specifications. Initial set should not take place in less than 45 minutes and final set should not require more than 10 hours. The hardening of portland cement continues for many months.

Uses. Portland cement is used as a cementing material in mortar and concrete. It is usually sold in bags or sacks containing 94 lb. or one cu. ft. loose volume with 4 sacks to the barrel.

ARTICLE 10. CONCRETE

Concrete is made by mixing portland cement and water with inert materials, such as sand, gravel, and crushed stone, which are called *aggregates*. The cement and water form a paste which, due to chemical action, sets and hardens binding the inert materials together to form a rocklike mass. In order to secure a durable concrete of the desired strength, and possessing other necessary characteristics, at a minimum cost, care must be exercised in selecting the materials, in determining the proportions of the various ingredients including water, in choosing the type of mixing equipment and controlling the mixing time, in transporting the concrete to the forms and in placing it in the forms, and in the treatment of the concrete for a period of several days after placing.

Materials. The portland cement used in concrete should be one which conforms to the specifications of the American Society for Testing Materials, although it must be recognized that all such cements are not alike in their behavior and properties. Special portland cements are often used to satisfy special conditions. If it is desirable to secure high strength quickly, as is often the case, *high early-strength cement* may be used; and if the amount of heat generated, by the chemical reactions which take place in setting, is objectionable, *low-heat cement* may be advantageous, particularly in massive structures from which heat escapes slowly. *White portland cement* is sometimes used to carry out desired architectural effects. It is manufactured by a special process using specially selected materials.

The water should be free from any injurious amounts of oils, acid, alkali, organic matter, or other deleterious substances but water which is suitable for drinking purposes will usually be satisfactory for making concrete. The surface water which is nearly always present in aggregates, even though they appear to be dry, must be allowed for in determining the amount of mixing water to be used. Also, if dry aggregate is used, corrections must be made for the amount of water which the aggregate will absorb. In any event, the quantity of water which is of importance is the net amount which actually enters the cement paste.

The inert material, called *aggregate,* is usually divided into two classes according to size. A common practice is to consider all aggregate which will pass a sieve with ¼-in. openings as *fine aggregate* and all which will be retained on a sieve of this size as *coarse aggregate,* but other size limits are in use. Aggregates which are graded in size so that the finer particles progressively fill up the voids in coarser particles have a smaller percentage of voids than aggregates which consist of particles that are uniform in size. For this reason, the graded aggregates are more economical because a smaller amount of cement paste is required to fill the voids. Specifications commonly contain clauses which insure the size grading of each aggregate.

Fine aggregate is usually sand, and coarse aggregate, gravel, or crushed stone but, when sand is not available, fine aggregate can be made by crushing sand in rolls. Crushed, air-cooled, blast-furnace slag is sometimes used for fine or coarse aggregate. Various special aggregates are used to produce concrete with special characteristics. Among those used to produce *lightweight concrete* are cinders and coke breeze which, because of their sulphur content, tend to corrode steel reinforcing and embedded steel pipes; burned clays and shales, which expand and become vitrified during the burning process; vermiculite ore, micaceous aluminum magnesium silicate, greatly expanded by sudden heat-

ing; and natural lightweight stones such as lava, pumice, and tufa. Aggregates which will produce *nailing concrete* into which nails can be driven and maintain their grip include asbestos fiber, sawdust, and cinders.

Concrete is sometimes made by using natural mixtures of sand and gravel just as they come from a gravel pit, with no attention paid to grading and without washing. This is called *pit-run gravel.* It is not a satisfactory aggregate because of the uncertainty concerning the quality of the resultant concrete. Better and cheaper concrete can normally be secured by giving attention to the grading because of the saving in cement which can usually be accomplished.

Aggregates should consist of clean, strong, hard, and durable particles, which are not coated with dust, clay, silt, or other substances, and which will not change in volume in the concrete under the action of water and which will not react chemically with the cement. Shale and some cherts are particularly objectionable because of their volume change or *unsoundness.* Flat, elongated, and angular particles, if present in large quantities, reduce the workability of concrete. Aggregates are screened to secure the desired gradings and washed to remove objectionable impurities which are in the finely divided state.

The maximum size of aggregate which can be used depends upon the character of the work. The size should not exceed $\frac{1}{5}$ the width or thickness of the member in which it is being placed or $\frac{3}{4}$ the clear space between reinforcing bars. A maximum size of 3 in., for use in any case, is often specified. Aggregates which are questionable should be tested because it may be impossible to make from them concrete of the desired quality, regardless of the proportions used. The tests which may be made include a sieve analysis and those for organic impurities, mortar strength, compressive strength of concrete cylinders, soundness, and resistance to freezing and thawing. The compressive strength of concrete is a good index of the quality of the aggregates used and of the durability, water-tightness, and other desirable qualities of the concrete itself.

Proportioning. The proportioning of materials used to form concrete has been the subject of much study and research and many methods for proportioning have been devised. A method which has been in vogue for many years and which will doubtless continue in use for a long period because of its simplicity and in spite of its shortcomings calls for *arbitrary proportions* which do not take into consideration the characteristics of the materials. Moreover, it pays little attention to the amount of water used. For example, a 1:2:4 concrete consists of 1 part cement to 2 parts fine aggregate and 4 parts coarse aggregate,

all measurements being by volume. This is not a satisfactory method for use on important work.

At the present time, emphasis is being placed on the *water-cement-ratio method* of proportioning. The strength of the cement paste which binds the aggregate particles together to form concrete is determined by the proportion of water used in making the paste. In order to obtain a plastic paste which is workable, much more water must be used than is actually necessary to satisfy the chemical changes which take place as the paste sets and hardens. However, increasing the propor-

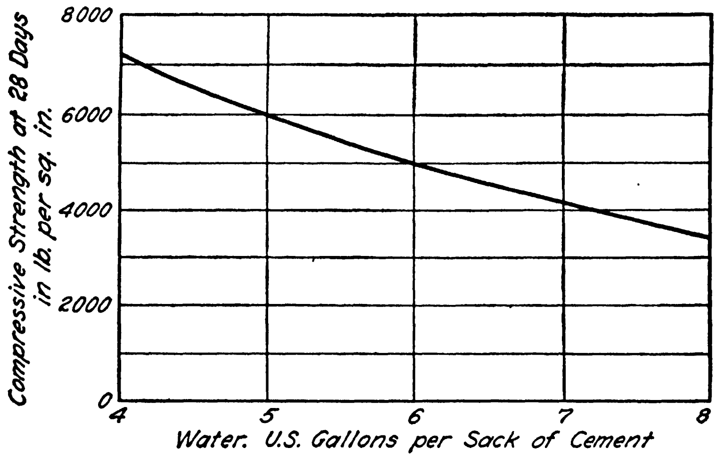


FIG. 10. Relation between Water-Cement Ratio and Compressive Strength[8]

tion of water beyond that required to produce the plastic mixture dilutes the paste and reduces its strength, as illustrated in Fig. 10, and its durability. This results in a reduction in the strength of the concrete made from that paste because the strength of the aggregates is usually greater than that of the paste and is therefore not a determining factor.

The ratio of the quantity of water to the quantity of cement is called the *water-cement ratio.* It is expressed in terms of United States gallons of water per sack of cement or as a ratio of the weight of water to the weight of the cement. Increasing the proportion of cement paste beyond that required to produce a workable mix does not increase the strength or durability of concrete. The proportion of cement paste required to produce a workable mix depends upon the grading of the aggregates. There is less total surface to be covered by the cement paste if the particles are coarse than if they are fine. It is therefore

desirable to use the lowest proportion of fine aggregate which will fill the voids in the coarse aggregate. An excess of coarse aggregate causes the mixture to be harsh and difficult to place. To correct this situation, there is a tendency to increase the amount of water. This reduces the strength and durability. The proper procedure is to increase the workability by better grading of the aggregates but, if this is not possible, the proportion of cement paste must be increased. Rounded aggregates produce a concrete which is more workable for a given water-cement ratio than those which are angular in shape. In other words, for the same workability, concrete composed of rounded aggregates has a lower water-cement ratio and therefore a higher strength than concrete made from angular aggregates.

As has been stated, the strength and durability of concrete are determined primarily by the water-cement ratio so that the proportioning of concrete, according to this method, consists essentially of selecting the water-cement ratio which will produce concrete of the desired strength and of the durability required by the conditions of exposure to which the concrete is to be subjected. The next step is to determine the amount and proportions of aggregate which can be added to a given amount of cement paste to produce a workable mix. The *consistency*, or state of fluidity, to give concrete the required workability in any case depends upon the job conditions. Concrete which is to be placed in a large mass without reinforcing bars can be stiffer than concrete which is to be placed in small, reinforced members. Also, vibrating the concrete in the forms, by means of special equipment designed for that purpose, permits the use of stiffer mixtures.

For exposed structures, the water-cement ratio is determined by the requirements of durability because concretes which are satisfactory in this respect usually have sufficient strength. The water-cement ratios recommended by the Joint Committee for varying degrees of exposure in different types of structures is given in the table on page 72.[10] From this table, it is seen that the water-cement ratio should be kept low where the exposure is severe. As noted in the table, for concrete not exposed to the weather, such as the interior of buildings and portions of structures entirely below ground, no exposure hazard is involved, and the water content should be selected on the basis of the strength and workability requirements. If tests show that the required strength is not developed by concrete with the water-cement ratios given in this table, a lower ratio must be selected.

The water-cement ratio required to produce concrete of the required strength can be determined by tests made with the materials to be used. If such tests are not made, the table of mixes, on page 73, recom-

WATER CONTENTS SUITABLE FOR VARIOUS CONDITIONS OF EXPOSURE IN GALLONS PER SACK OF CEMENT

(From 1940 Report of Joint Committee)[10]

<table>
<tr><th rowspan="3">Type or Location of Structure</th><th colspan="5">Severe or Moderate Climate, Wide Range of Temperatures, Rain and Long Freezing Spells, or Frequent Freezing and Thawing</th><th colspan="5">Mild Climate, Rain or Semi-Arid, Rarely Snow or Frost</th></tr>
<tr><th colspan="2">Thin sections</th><th colspan="2">Moderate sections</th><th rowspan="2">Heavy and Mass sections</th><th colspan="2">Thin sections</th><th colspan="2">Moderate sections</th><th rowspan="2">Heavy and Mass sections</th></tr>
<tr><th>Reinf.</th><th>Plain</th><th>Reinf.</th><th>Plain</th><th>Reinf.</th><th>Plain</th><th>Reinf.</th><th>Plain</th></tr>
<tr><td>A. At the waterline in hydraulic or waterfront structures or portions of such structures where complete saturation or intermittent saturation is possible, but not where the structure is continuously submerged:
In sea water
In fresh water</td><td>5
5½</td><td colspan="2">5½
6</td><td colspan="2">6
6½</td><td>5
5½</td><td colspan="2">5½
6</td><td colspan="2">6
6½</td></tr>
<tr><td>B. Portions of hydraulic or waterfront structures some distance from the waterline, but subject to frequent wetting:
By sea water
By fresh water</td><td>5½
6</td><td colspan="2">6
6½</td><td colspan="2">6
6½</td><td>5½
6</td><td colspan="2">6½
7</td><td colspan="2">7
7½</td></tr>
<tr><td>C. Ordinary exposed structures, buildings and portions of bridges not coming under above groups</td><td>6</td><td colspan="2">6½</td><td colspan="2">7</td><td>6</td><td colspan="2">7</td><td colspan="2">7½</td></tr>
<tr><td>D. Complete continuous submergence:
In sea water
In fresh water</td><td>6
6½</td><td colspan="2">6½
7</td><td colspan="2">7
7½</td><td>6
6½</td><td colspan="2">6½
7</td><td colspan="2">7
7½</td></tr>
<tr><td>E. Concrete deposited through water</td><td>*</td><td>*</td><td>5½</td><td colspan="2">5½</td><td>*</td><td>*</td><td>5½</td><td colspan="2">5½</td></tr>
<tr><td>F. Pavement slabs directly on ground:
Wearing slabs
Base slabs</td><td>5½
6½</td><td>6
7</td><td>*
</td><td colspan="2">
*</td><td>6
7</td><td>6½
7½</td><td>*
</td><td colspan="2">
*</td></tr>
</table>

G. Special cases:
(a) For concrete exposed to strong sulfate ground waters, or other corrosive liquids or salts, the maximum water content should not exceed 5 gal. per sack.
(b) For concrete not exposed to the weather, such as the interior of buildings and portions of structures entirely below ground, no exposure hazard is involved and the water content should be selected on the basis of the strength and workability requirements.

* These sections not practicable for the purpose indicated.

mended by the Joint Committee[10] for various probable minimum allowable compressive strengths may be used as a guide.

Compressive Strengths for Various Water-Cement Ratios

(Mixes Recommended by Joint Committee)[10]

Maximum Allowable Net Water Content, Gal. per Sack of Cement	Probable Minimum Allowable Compressive Strength at 28 Days, Lb. per Sq. In.
5	5000
5½	4500
6	4000
6½	3600
7	3200
7½	2800
8	2500
8½	2000

The consistency required in any case is commonly specified by means of the *slump test,* which is a convenient measure of the degrees of plasticity or workability. In making this test a sample of concrete is taken from the mixer and placed in an open-ended, sheet-metal mold shaped like the frustrum of a cone. It is 12 in. high with a top diameter of 4 in. and a bottom diameter of 8 in. and rests on a flat surface. The concrete is placed through the open top in three layers, rodded in a specified manner, and the top surface is struck off even with the top of the mold. The mold is immediately removed by lifting vertically. The distance which the top surface of the concrete drops is called the *slump.* A stiff mixture obviously will have a small slump and a fluid mixture a large slump.

As stated in the 1940 Report of the Joint Committee,[10] the appropriate consistency and the maximum size of aggregate which should be used depend upon the conditions which prevail. The governing factors are the available materials, the size of the member, the quantity of the concrete, the arrangement of reinforcement, and the procedures in transporting and placing the concrete. The aggregate sizes and the consistencies suitable for several different classes of work, as suggested by the Committee, are given in the table on page 74.

CONSISTENCIES AND AGGREGATE SIZES

(As Suggested by Joint Committee)[10]

Portion of Structure	Consistency-Slump		Maximum Size of Coarse Aggregate, In.
	Maximum, In.	Minimum, In.	
Reinforced foundation walls and footings	5	2	$1\frac{1}{2}$
Plain footings, caissons and substructure walls	4	1	2
Slabs, beams, and reinforced walls	6	3	1
Building columns	6	3	1
Pavements	3	2	2
Heavy mass construction	3	1	3 to 6*

* In making the slump test, all aggregate larger than 2 in. should be screened out of the mixture.

From this table it is seen that stiff concrete with a small slump and large maximum coarse aggregate is suggested for massive members and unreinforced slabs, while more fluid concrete with small maximum coarse aggregate is suggested for small reinforced members.

Bulking. The volume of a given quantity of sand may be much greater when damp than when dry. This increase in volume due to increase in moisture content is called *bulking*. When the weight of the moisture reaches about 6 per cent the weight of the sand, the bulking may be as high as 20 to 30 per cent. Further additions tend to decrease the amount of bulking until the sand is completely inundated when there is practically no bulking. The bulking of fine material is more for a given percentage of moisture than that of coarse material. Coarse aggregate bulks very little. Methods of measuring sand should be such as to avoid the effect of bulking.[8]

Mixing. Concrete is usually mixed by power-driven machines which turn out the concrete in *batches*. These contain from 2 cu. ft. for the smallest mixers to 4 cu. yd. for the largest mixers. The strength and uniformity of concrete increases with the mixing time but the improvement after the first minute or two, measured from the time when all the materials are in the mixer, is not usually considered enough to justify longer mixing times. When the quality of concrete is of unusual importance, as in structures which are to be watertight or which are subject to severe exposure to conditions, it may be desirable to improve the quality and uniformity of the concrete by increasing the time of mixing. The speed of rotation of the mixing drum, within reasonable limits, has little effect on the quality of the concrete.

In many cities, concrete can be purchased from *central mixing plants* which deliver mixed concrete to the job in dump trucks. Where there is likely to be considerable delay in the placing of concrete from central mixing plants, the concrete may be placed in an *agitator* where it can be kept in a workable condition for an hour or more. No water should be added in the agitator. The ingredients for concrete, excepting the water, may be mixed in a *central batching plant* and dumped into *transit mixers* mounted on trucks where the water is added and the mixing completed while the concrete is on its way to the job.

Transporting. Concrete is transported from the mixer to its place in the forms by wheelbarrows, two-wheeled buggies, bottom-dump buckets, dump cars, dump trucks, and chutes, or it may be pumped through steel pipes. The method used is selected after consideration is given to the quantity to be placed, the layout of the job, the equipment available, and other factors. The method employed and the procedure in its operation must be one which prevents the separation of the materials, called *segregation,* and insures that concrete of good quality is deposited in the forms. The use of long chutes has fallen off during recent years because segregation of the materials is likely to occur in the chutes, but short chutes are not objectionable from this point of view.

Placing. Before concrete is placed, the forms should be carefully cleaned out and, except in freezing weather, the forms should be thoroughly sprinkled unless oiled forms are used. The concrete should be so placed that no segregation occurs. Dropping concrete is objectionable because of segregation and because air is trapped in the concrete. The concrete next to the forms should be spaded and tamped to prevent honeycombing and to improve the appearance of the exposed surface, but these operations should not be carried too far or segregation will result.

Concrete is said to be *honeycombed* when it contains areas where the coarse aggregate is not surrounded with fine aggregate and mortar. When excess water is used, fine inert particles from the cement and aggregate, called *laitance,* accumulate in the water on the top surface of concrete. As this water evaporates, this fine inert material is deposited and, if it is not removed, forms a plane of weakness. Also, because of the excess water, or *water gain,* the concrete below the thin layer of laitance is usually porous and lacks durability. The formation of laitance should be prevented by avoiding excess water rather than trying to remove the laitance after it has formed.

The quality of concrete can be improved by means of *vibration* which assists in its consolidation. Some types of *vibrators* are attached to

the forms, others are placed on the surface of the freshly deposited concrete such as slabs and pavements, while others are inserted in the concrete. They may be driven by electricity or compressed air. If vibrators are used, the concrete can be stiffer with a smaller slump and therefore can have a lower water-cement ratio and still be placed satisfactorily. This results in stronger and more durable concrete from the same materials. If strength is the controlling factor, leaner mixes can be used when the concrete is vibrated and the same strength secured. Vibration also facilitates the flow of concrete around closely spaced reinforcement and into places which would be difficult to reach by ordinary methods.

Concrete which has partially hardened should never be used even though its plasticity is restored by *retempering,* which consists of adding water and remixing.

The placing of concrete under water should be avoided if possible. However, if concrete must be placed in this manner, a procedure must be adopted which will not require the concrete to fall through the water, because this would wash out the cement. Two devices for depositing concrete under water are in use, i.e., the bottom-dump or drop-bottom bucket and the tremie. The *drop-bottom bucket* is so arranged that the bottom opens when it touches the surface on which the concrete is to be deposited or previously has been deposited. The *tremie* is a steel pipe long enough to reach through the water to the points where the concrete is to be deposited. In starting operations, the bottom is plugged to exclude water and to retain the concrete with which it is filled. It is then lowered into position with the lower end at the point where the first concrete is to be deposited. The plug is then forced out and concrete flows out the bottom of the pipe to its place in the forms, without passing through the water. Concrete is supplied at the top of the pipe at a rate sufficient to keep the pipe always filled. The rate of flow of concrete in the pipe is controlled by changing the length of embedment of the lower end of the pipe in the deposited concrete. The upper end of the pipe may be funnel-shaped or else a hopper may be provided to facilitate placing concrete in the tremie. Care must be exercised to keep the tremie from losing its charge and from filling with water because this will usually necessitate starting again with the plugged tremie. Some engineers, however, if a richer concrete is used, permit the operation to continue while the water is being forced from the tremie by the concrete, the additional cement being used to take the place of that washed out of the concrete by the water in the tremie. After the concrete is placed, it is not spaded or puddled as is done with concrete in air.

Curing. The chemical reactions which take place as cement hardens continue for a very long period if conditions remain favorable. This results in a gradual increase in the strength of the concrete and an improvement in other properties. In order for these reactions to continue, moisture must be present and the temperature must be favorable. An excess of water is always present when the concrete is placed. If the evaporation of this water is prevented or reduced, the water necessary to continue the chemical operations will probably be present. Evaporation is reduced by covering the surface with wet burlap, by sprinkling, by coating the surface with a waterproof paint, by covering slabs with sand or earth which is kept moist, and in other ways. This protection against evaporation should be continued for 5 days or longer.

Concrete must be protected from freezing at least during the first 72 hours after being placed. The heat generated by the chemical reactions of the concrete is an important factor in maintaining desirable temperatures. The mixing water may be heated and, if more heat is required, the aggregates may also be heated, especially to remove the frost and ice. Specifications often require that concrete be maintained above 70 deg. fahr. for the first 3 days after placing and above 50 deg. fahr. for the first 5 days, but the materials should not be heated enough to raise the temperature of the concrete above 100 deg. fahr. After concrete has been placed it can be protected by enclosing in some manner and maintaining heat in the enclosed space. Covering a temporary frame work with canvas *tarpaulins* is a common method. The heat may be supplied by steam which is allowed to escape into the enclosed space to provide moisture for curing. *Salamanders,* which are crude coke-burning stoves, are simple in operation but difficult to control.

The freezing point of concrete can be lowered by the use of salt or other chemicals but this practice is objectionable. Because of the heat it generates and because of its insulating value, manure is sometimes used to protect concrete from freezing. However, manure should not be applied directly to concrete.

Concrete should never be placed on frozen ground because settlement may occur when the ground thaws. All ice and frost should be removed from forms before concrete is placed in them.

Gunite. " Gunite is a surface coating of mortar which consists of an intimate mixture of portland cement and moist sand, subsequently combined with water and placed under pneumatic pressure."[8] Gunite is applied by means of a cement gun which is held in the hand about 3 ft. from the surface and which directs the mortar stream with considerable force against the surface to be coated. A considerable portion spatters

and is wasted. The sand and cement are mixed in a Gunite machine and forced through a hose to the gun by compressed air. Water under pressure is supplied by another hose and is mixed with the sand-cement mixture at the gun. The mortar formed by these materials is forced upon the surface being treated with Gunite.

Gunite forms a hard, dense, durable coating but the surfaces to which it is applied must be clean and solid and moistened with water just before the Gunite is applied. The Gunite layer must be properly cured by being kept moist for two weeks and by protecting it from the sun. Gunite is also called *pneumatically applied mortar.*

ARTICLE 11. ROCK AND STONE

General Discussion. The term *rock* is used by the geologist to include both the solid and unconsolidated material forming the earth's crust, the former being designated as *bed rock* and the latter as *mantle rock.* In its engineering usage, the term *rock* includes only the solid or bed rock, the unconsolidated material being called *soil* or *earth.* In agriculture, the term *soil* applies only to the few inches of surface or *top soil* which supports vegetation, the underlying material being known as *subsoil.*

The terms *rock* and *stone* are often used synonymously, but there is actually some distinction between them. Both of these terms apply to the same material but, in general, if geologic formations are being considered the term *rock* is used while smaller or quarried pieces of rock are called *stone.* However, these distinctions between rock and stone are not always made as could be illustrated by many examples of established usage.

Rock formations are of interest to the structural engineer because they are used to support the foundations of many of his structures and stone is of interest to him because of its use in stone masonry, as concrete aggregate, in the manufacture of many materials he uses and in numerous other ways.

Rocks are divided into three classes according to the method of formation. These classes are igneous, sedimentary, and metamorphic. They are also divided into classes according to their chemical composition. The most important of these classes are argillaceous, siliceous, and calcareous. *Argillaceous rocks* are composed primarily of alumina (Al_2O_3), which is the chief component of clay. *Siliceous rocks* are composed primarily of silicon dioxide (SiO_2), which is the principal ingredient of quartz sand. *Calcareous rocks* are composed primarily of calcium carbonate or lime ($CaCO_3$).

The earth's crust is made up almost entirely of eight chemical elements according to F. W. Clarke.[11] These are estimated to be present in the following amounts:

CHEMICAL ELEMENTS IN EARTH'S CRUST

Oxygen	47.0 per cent
Silicon	28.1
Aluminum	8.2
Iron	4.6
Calcium	3.5
Magnesium	2.6
Sodium	2.6
Potassium	2.3
	98.9 per cent

From this table, it can be seen that oxygen comprises nearly one-half the earth's crust and silica over one-quarter. These elements exist in combination with many other elements to form the minerals mentioned in the next paragraph.

Nearly all rocks are made up of one or more *minerals,* which are definite chemical compounds usually with crystalline structures, but some consist of natural glass or volcanic dust. The most common rock-making minerals are: *quartz,* which is silicon dioxide; the *feldspars,* which are potassium, sodium, or calcium aluminum silicates; the *micas,* which are complex hydrous silicates of aluminum with other elements such as potassium, magnesium, and iron; *hornblende,* which is primarily calcium magnesium silicate; *kaolinite,* which is hydrous aluminum silicate; *calcite,* which is calcium carbonate; and *dolomite* which is magnesium carbonate.

Igneous Rocks. Igneous rocks are those formed from the solidification of molten rock. If this solidification occurs below the earth's surface, the rock is called *plutonic* or *intrusive,* but, if it occurs on the surface, *volcanic* or *extrusive rock* is formed. If the molten rock is erupted violently into the air, *pyroclastic rocks* are formed. The term *lava* is also applied to solidified extrusive rock. The molten rock, from which igneous rocks are formed, consists of a hot solution composed principally of feldspar, quartz, mica, and gases such as water vapor and carbon dioxide. The solidification of igneous rocks is due to a decrease in both temperature and pressure. Their texture is influenced greatly by the rate of cooling and by the volatile substances present. It may be coarse-grained if the cooling is very slow and fine-grained if the cooling is somewhat more rapid. If the cooling is very rapid, a *glass* is formed. The volatile substances facilitate crystallization.

Extrusive sheets have a vesicular or porous structure owing to the gases trapped in the mass as it solidifies.

The more common igneous rocks are granite, felsite, basalt, and obsidian. *Granite* is usually a strong, durable, non-porous, and practically insoluble rock which is a desirable foundation and building material. *Felsite* is a light-colored, fine-grained, volcanic rock which usually occurs as dykes or lava sheets. It is usually less porous than basalt but may cause considerable leakage if located under a dam or in a reservoir. *Basalt* is a dark-colored rock which occurs chiefly in lava sheets or dykes. It is likely to be porous, cavernous, and may be badly fractured. Because of the danger of leakage, basalt is a treacherous material on which to build a dam or to locate a reservoir. It is practically insoluble, the caverns being due to its method of formation and not to the solvent action of water as is true of limestones. *Obsidian* is a volcanic glass formed by rapid cooling of molten rock. *Pyroclastic rocks* include *volcanic ash,* which is composed of fine, glassy particles deposited at considerable distance from the volcano by which they were formed; *lapilli,* which are formed from the gravel-like particles deposited closer to the volcano; and *breccias* and *tuffs,* which are formed by consolidation of the coarser particles falling near the volcano. The volcanic material corresponding in fineness to sand is known as *puzzolana*. *Trap* or *trap rock* is a commercial term applied to certain fine-grained, dense, durable igneous rocks, such as basalt, which are very difficult to quarry and work and so are not suitable for building stone but can be crushed for use in road surfacing and for railroad ballast.

Sedimentary Rocks. Sedimentary rocks are formed from the disintegration products derived from igneous rocks or from other sedimentary rocks. This disintegration is brought about by the action of weathering agencies. The principal *weathering agencies* are: *temperature changes,* which cause cracking due to unequal coefficients of expansion of the minerals that compose a rock and also due to unequal temperatures in different parts of a rock mass; *alternate freezing and thawing,* which, because of the increase in volume of water when freezing in the pores of the rock, exerts a repeated disruptive action; *abrasion* resulting from the action of moving glacial ice, running water, and wind, with their effectiveness accelerated by the solid particles which they carry; and *chemical action* of atmospheric gases and of rain water which has absorbed atmospheric gases or ground water carrying chemicals in solution.

These products of rock disintegration may remain in place or may be transported by running water, wind, or glacial ice and may be de-

posited as sediments. These deposits may remain unconsolidated, as soil, or may be solidified through pressure exerted by overlying material and through the action of cementing materials included in the deposits or supplied subsequently by infiltration. Other important factors in the formation of rocks are the sea organisms, which form their shells from calcium carbonate originally derived from rocks, transported by water, and carried in solution in sea water. These shells accumulate on the sea bottom as the organisms die, are ground by the movement caused by shifting currents, and become solidified by pressure and the cementing action of the calcium carbonate itself. The time required by this continuous cycle of rock disintegration, transportation, deposition, and solidification to form rock again is measured in thousands of years.

Characteristic of sedimentary rocks are the layers or *strata* into which they are divided. The process of deposition of a given deposit has rarely been uniform and continuous but variations have occurred in the velocity of the water, or the wind which is of less importance, and, therefore, in the size and composition of the material carried in suspension or the composition of the material carried in solution. These variations have resulted in the division of deposits into layers which differ somewhat from each other. The dividing surfaces between these strata are called *bedding planes* or *beds*. On account of this division into strata, many sedimentary rocks are also called *stratified rocks*, but some limestones show so little stratification that they are called *freestones*, their structure being uniform in all directions. The *beds* between strata may be planes of weakness so far as shearing forces are concerned, particularly if they contain clay which, when it is wet, becomes very slippery. Since movement may take place easily along such surfaces, they are sometimes called *gliding planes*. Sedimentary rocks are formed chiefly of the minerals quartz, kaolinite, calcite, and dolomite. The more common sedimentary rocks are sandstone, conglomerate, limestone, and shale. (See Art. 26.)

Sandstones are formed by the consolidation of beds of sand which have been deposited by water carrying sand in suspension. The consolidation has been due to pressure exerted by overlying material and to a cementing material which may be clay, calcium carbonate, iron oxide, or silica. The character of the cementing material has a pronounced effect on the properties of sandstone, those in which silica is the cementing material being the strongest and most durable. The properties are also affected markedly by the degree of cementation which may vary greatly. Pure sandstone is silicon dioxide. Sandstones may gradually grade into shales as the grain size becomes smaller. *Con-*

glomerates are similar to sandstones but consist of cemented gravel instead of cemented sand. *Pudding stone* is conglomerate in which the pebbles are well rounded and in *breccia* they are angular. Sandstones which are pure silicon dioxide are white in color, the various shades of yellow, brown, and red being due to the presence of different iron oxides.

Limestones are sedimentary rocks formed chiefly from the accumulation of shells on ancient sea bottoms which may now be many miles inland. Some limestones show fossils but others show no trace of their origin because of the fine grinding to which the shells were subjected after deposition. The cementing material is calcium carbonate. Limestone, when pure, is calcium carbonate but magnesia, silica, alumina, and iron oxide are present in varying amounts. *Travertine* is a limestone formed by the chemical precipitation of calcium carbonate from hot ground water. A characteristic of this stone is the small irregularly shaped cavities it contains. All limestones are slightly soluble in water. This is not a defect of any importance in connection with building stones or foundations. However, during past geologic periods, *solution channels* and *caverns* may have been formed in a limestone deposit. The most common color of limestone is gray but it may also be buff and brown.

Shales are formed by the compacting only or by the compacting and cementing of clays, muds, and silts and may grade into sandstones if a large amount of siliceous material is present or into limestone if they are formed from silts containing an abundance of calcareous material. They have a finely stratified structure and are quite impermeable. Those that have been formed by compaction without cementation slack and disintegrate when acted upon by water after partial or complete drying. This characteristic may cause the rejection of such a formation as a dam site.[12] These shales are also unsatisfactory for supporting heavily loaded foundations because they gradually flow under load. This phenomenon is known as *plastic flow*. Shales in which the grains have been cemented as well as compacted by pressure do not disintegrate, as do the shales which have been compacted only, and are not subject to plastic flow. For these reasons they are more satisfactory to support foundations. Shales do not possess the requisite durability for building stones.

Metamorphic Rocks. Metamorphic rocks are either igneous or sedimentary rocks whose physical or chemical characteristics have been altered by the action of pressure resulting from earth movements or from temperature changes caused by intrusions of molten rock or by vapors or liquids which have permeated the rocks. The changes which

occur are in mineral composition, texture, and structure, and include cementation by siliceous matter. The changes in mineral composition depend upon the chemical composition and, since all kinds of rocks may be subjected to metamorphic action, there is a wide range of variation in the mineral composition of metamorphic rocks. Such rocks are highly crystalline in structure regardless of their origin. They commonly have a *foliated* or laminated structure similar to the stratified structure of sedimentary rocks, and if so they are known as *schists.* The common metamorphic rocks are *gneiss,* a laminated rock with a mineral composition similar to granite; *schist,* a laminated crystalline silicate rock which splits easily; *slate,* a fine-grained argillaceous rock which splits easily into slabs; *quartzite,* a hard durable crystalline quartz rock derived from sandstone; and *marble,* a crystalline rock which can be polished and which is derived from limestone and is therefore composed chiefly of calcium carbonate. There is no definite line of demarkation between many of the metamorphic rocks. For instance, sometimes schist may grade into gneiss and into slate at other times. In the building industries limestones which can be polished are commonly classed as marbles.

Rock Structure. The methods of formation of the various rocks have been considered. After rocks have been formed their structures may be greatly changed by movements of the earth's crust so that the formations become bent and fractured as shown in Fig. 11*a*. The bends which have been formed are called *folds,* and the fractures are called *joints* if there is no movement along the fracture, or *faults* if the rocks on one side of the fracture have moved with reference to the rock on the other side, as shown in Fig. 11*b*. The rock adjacent to a fault may be broken into fragments, as shown in Fig. 11*c,* which may afterward become cemented together forming fault breccia, or it may become finely pulverized and then it is called *gouge.* Sedimentary rocks are usually deposited in horizontal layers or *strata,* as has been explained, but owing to the folding previously referred to, they are found at various slopes. The angle which a bed makes with the horizontal is called the *dip,* and the direction of the line of intersection of the bed with a horizontal plane is called the *strike,* as shown in Fig. 11*d*.

Because limestone is soluble, there is always the possibility that a limestone formation will be *cavernous* or contain *solution channels,* owing to the action of ground water. Such defects are particularly objectionable in dam or reservoir sites because of the danger of leakage, but they may cause failure of building foundations, bridge piers, or any other structure located immediately above such an opening. If defects of this type are discovered before a structure is built, they can usually

be remedied by pressure grouting, by cleaning out the openings and filling with concrete, or by other means.

Occasionally large areas will be encountered whose rock formations have been broken up and the rock crushed to great depths even though there may be little evidence of such action on the surface. Such areas are called *shear zones.* They are particularly objectionable when they

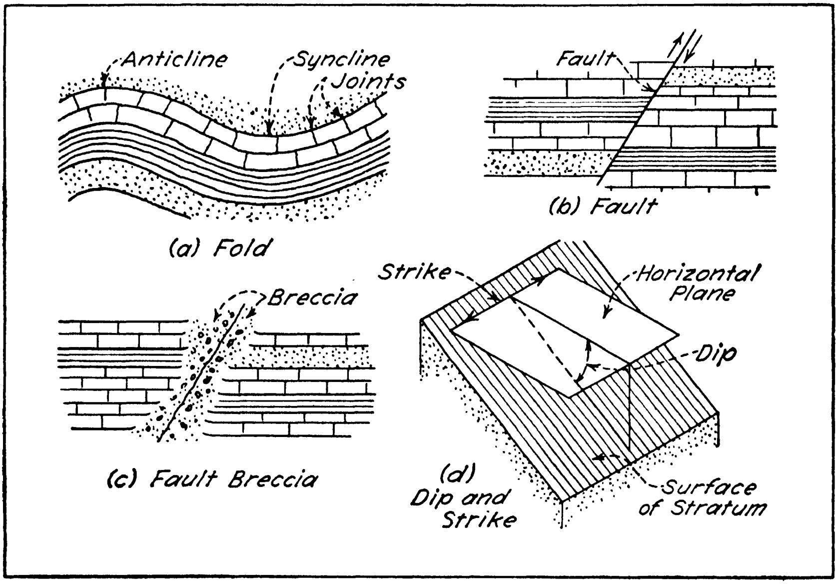


FIG. 11. Rock Structure

occur in proposed dam or reservoir sites or in tunnel locations and usually would cause the abandonment of such sites for the proposed use.

Physical Properties. The physical properties of stone, which are of primary importance in connection with the use of stone in its natural position to support foundations or in masonry structures are: strength, durability, permeability, solubility, workability, fire resistance, color, and appearance. Some of these have been considered in the preceding paragraphs to which the reader is referred. (Also see Art. 26.)

Strength is an important property of rocks whether they serve to support foundations or are built into stone masonry. Sound bed rock is usually strong enough to support any load which can be carried to it by a concrete pier. Also, stone of such quality that it is durable when exposed to weathering in a masonry wall is usually strong enough to support the loads which it is called upon to carry. The loads which are placed on rock formations and stone masonry are principally com-

pressive but the flexural or bending strength is of importance in stone lintels over openings and in resisting stresses caused by unequal settlement and improper bedding of the individual stones. Stone is not used in a manner that will subject it to tensile stresses. The compressive strengths of rock or stone may vary from very low values up to 50,000 lb. per sq. in., or more, so no specific values can be given. Stratified rocks have greater compressive strength normal to their bedding planes than parallel to them. Tests would be required if the strength of a given stone were in question. However, most rocks or stones which would be considered for foundations or construction purposes would be found amply strong for the loads they are to carry.

The *durability* of building stone is probably its most important property. Building stones are acted upon by most of the weathering agencies which act on rock formations. These have been described in preceding paragraphs. The rate of weathering depends upon the composition, texture, and structure of the stone. The durability of sandstone depends largely upon the kind of cementing material which holds the grains together, silica being the most durable and clay, usually, the least. Limestone and marble are slowly soluble in water containing carbon dioxide, but the rate at which these stones dissolve is usually so slow that this action is of no importance in building stones. However, this factor may receive consideration if polished surface is to be maintained as marble. Also the possibility of solution channels and caverns in limestone that supports foundations must be investigated.

The *porosity* of a building stone, which is the proportion of pore volume to the total volume, is often taken as an indication of its resistance to frost action. However, it is not the amount of pore space that is of importance but its continuity as measured by its *permeability*, which is its ability to permit water to pass through its pores. A stone may be very porous and still be quite impermeable, because of lack of continuity in the pores. For this reason it may not be seriously affected by alternate freezing and thawing. Moreover, an open, free-draining texture may be more resistant to frost action than a fine texture which holds water in the pores by capillary action.

The best method for determining the durability of a stone is by examining outcrops or the parts of a quarry where the stone has been exposed for a long period. Similarly, the examination of the same rock in structures which have been in existence for many years is a good index of its weathering properties. Other properties which may indirectly give some indication of the durability of a stone are its weight and its compressive strength, high values for these properties usually, but not always, being favorable. Accelerated freezing and thawing

tests carried on in the laboratory are also of value. *Brard's Test* is often taken as an indication of the resistance of stones to frost action. It consists of crystallizing sodium sulphate in the pores of a stone by soaking or boiling the stone in the salt solution. The specimen is then dried and the sodium sulphate crystallizes and expands in the pores where it exerts a disruptive action similar to that of freezing water. The salt also exerts a chemical action which is not present in the case of water. This operation is repeated and its effect on the stone observed. This test is much more severe than alternate freezing and thawing.[13] Blocks of stone that have been quarried for a short time may contain a considerable amount of water called *quarry sap*. Such stones are frequently broken by freezing, but if allowed to season this difficulty will probably not be experienced.

In some cases, the *fire resistance* of a stone may be an important consideration. No building stone will stand very high temperatures. This is particularly true when the heated stone is subjected to a stream of water, as frequently happens in burning buildings. On account of its low resistance to fire, the use of stone for interior piers, caps, and bond stones is sometimes prohibited by building codes, but this practice is probably too severe. Building stones may be arranged in order of their fire resistance as follows: fine-grained sandstone with silica binder; fine-grained granite or oolitic limestone; ordinary limestone; coarse-grained granite; marble. Limestone fails by calcination at a relatively low temperature.

Workability is another important property of building stones. Stones which are durable, strong, and attractive in appearance may not be suitable for building purposes because of the labor required to work them into the desired shapes. Some stones which would not be suitable for ashlar may be satisfactory for rubble or squared-stone masonry which requires a relatively small amount of labor in shaping. Stones soft enough to work readily are frequently not durable. Ornamental work such as moldings and carvings requires a stone with an even grain which is free from seams and other defects. Stones easily worked in any direction and free from stratification are called *freestones*. Stones which have been recently quarried may contain a considerable amount of water known as *quarry sap*. They are more easily worked when they are *green* than after they have seasoned and the quarry sap has drained out and evaporated.

Abrasive resistance is of importance in steps, doors sills, and floors.

The *color* of a stone may be a determining factor in its selection for a given building. (See Art. 26.)

ARTICLE 12. SOIL

Formation of Soils. As explained in the preceding article, the upper part of the earth's surface consists of solid rock called *bedrock* which is exposed or is overlaid with water or unconsolidated material, called *soil* or *earth* by the structural engineer, formed by the weathering of the solid rock. This unconsolidated material may rest on the rock from which it was derived, and gradually grade into that rock, or it may be eroded and transported by water, wind, or glacial ice and deposited at some more or less remote point. Soil which remains in position over the rock from which it was formed is called *residual soil.* That which has been transported by water and deposited at another site is called *alluvial soil* or *alluvium.* The sizes of the particles in soil transported by water depend upon the velocity of the water from which they are deposited, the size of grains deposited decreasing as the velocity of the water decreases. Changes in velocity may take place gradually along a water course and result in fairly uniform deposits over a wide area or they may take place quickly within a short distance and produce deposits with marked variations. Because of the method of formation, soil deposits are usually arranged in layers or are *stratified.* An important soil type formed by wind-blown material is known as *loess.* Owing to the way it was transported, loess consists of fine particles. Rock fragments and particles of all sizes which had fallen on glaciers, or had been picked up by them as they moved forward, were finally deposited as the glaciers melted and formed *moraines* of perhaps considerable size. These deposits may be in the form of ridges, called *terminal moraines,* crossing valleys and located where the forward movement of a glacier was just balanced, for a considerable period of time, by the rate of melting; they may be *lateral moraines,* which are ridges, paralleling the valley, formed by debris deposited along the sides of glaciers as they melted. Or the debris, if deposited to considerable depth over a wide area as a glacier receded by melting, would form *ground moraines.* Unless modified by subsequent action of water, the material deposited consists of material of all sizes mixed together in an unstratified mass called *till.* Fine particles, ground off bed rock as a glacier moved over it and deposited when the glacier melted, are known as *rock flour.*

Classification of Soils. As stated previously, soils have been formed by the disintegration of igneous rocks or sedimentary rocks which were, in turn, formed by the solidification and cementation of unconsolidated materials originally derived from igneous rocks. Soils may also be formed from the disintegration of metamorphic rocks derived from igneous or sedimentary rocks as has been explained.

The two principal classes of soil are *sand* and *clay*. Silt which is intermediate between these two resembles sand in its behavior more than clay. There is a great variety of intermediate soils which are mixtures of these three types of soil with or without relatively small proportions of other materials. Some mention of these is made later but they will not be considered in detail. The chemical composition of sand is silicon dioxide and of clay, hydrous aluminum silicate with various impurities.

The individual grains of which sand is composed are usually relatively large while those of clay are extremely small, the finest grains being submicroscopic in size or too small to be distinguished under the most powerful optical microscope. The difference in grain size has led to the classification of soils according to grain size, as follows:

CLASSIFICATION OF SOILS ACCORDING TO GRAIN SIZE

Sands	2.00 to 0.05 mm.	or $\frac{1}{12}$ to $\frac{1}{500}$ in.
Silts	0.05 to 0.005 mm.	or $\frac{1}{500}$ to $\frac{1}{5000}$ in.
Clays	Less than 0.005 mm.	or $\frac{1}{5000}$ in.
Colloids	Less than 0.001 mm.	or $\frac{1}{25,000}$ in.

The classification of soils according to grain size is convenient because *mechanical analyses* are relatively simple to make, but it is unsatisfactory because grain size is only one factor, and probably not the most important, determining the behavior of soils as it affects engineering works. Sand may be ground to a fineness which would lead to its classification as clay according to grain size, but this finely ground sand will not possess the properties, such as cohesion and plasticity usually associated with clay.[17]

Another objection to mechanical analysis concerns the methods used. The proportion of particles of the various sizes larger than about 0.074 mm., which is the size which will pass a 200-mesh sieve, can be determined satisfactorily by means of sieves, but the size distribution of the smaller particles must be determined by indirect methods, depending upon the relation between the size of particle and its rate of settlement in water. This procedure does not give true results because the shape of particle as well as the size affects the rate of settlement, because an envelope of water clings solidly to each particle and reduces its rate of settlement, and because of other factors. In the size classi-

fication of soils, those particles of the clay size range which have a grain size less than $\frac{1}{1000}$ mm. or $\frac{1}{25000}$ in. are classed as *colloids*. Particles of this size remain in suspension in water indefinitely even though they have a greater specific gravity than water.[18] The colloidal content of a soil has pronounced effects on its properties, but engineers usually measure these properties directly rather than attempt to predict them from the colloidal content.

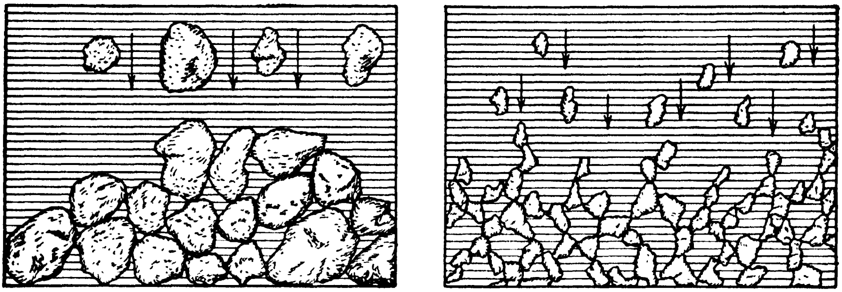
Particle Shape. A factor which is more important than the size of the soil grains in determining the physical properties is the *shape* of the grains. Sand and silt grains are roughly spherical or bulky while clay grains are flat, flaky, or scalelike. One result of this difference in shape is the high compressability of clay as compared with that of sand.

Structure of Soil. The *structure* of a soil deposit also bears an important relation to its properties. When sand grains are deposited in water they are carried by gravity into positions which result in relatively dense deposits while it is commonly considered that the fine clay grains attach themselves to other clay grains without being carried by gravity down to positions which would result in high density. These processes are illustrated in Fig. 12.[24] It is seen that a clay deposit consists of a sort of mesh or network of solid grains with the intervening spaces called *voids* or *pores* filled with water. Loads are transmitted through the deposit along the network which, as it yields, increases the pressure in the water in the pores and this is called the *pore pressure*. If the network is broken up by disturbance of any kind, the grains become surrounded or partially surrounded with water and the soil mass loses a part of or all the rigidity, in which event it is said to be *disturbed* or *remolded*. Samples of clay obtained without changing its structure are called *undisturbed samples*. They are difficult to obtain and require specially designed apparatus.

Voids in Soil. A mass of soil consists of solid particles with intervening spaces called *voids*. The voids may be filled with air or other gas, with water, or partially with air or other gas and partially with water. The specific gravity of the grains is about the same regardless of their composition or size, generally falling between 2.5 and 2.8. Even though the specific gravity of the grains of most soils is fairly constant, the weight of a cubic foot of soil may be as low as 70 lb. or as high as 150 lb., because of differences in proportions of voids, depending upon the grading of the grain sizes; the moisture content, the extent to which it has been *consolidated* or compressed by overlying material or superimposed loads, or has been *compacted* by rolling, tamping, or vibrating. Voids are also called *pores*.

In a volume of equal spheres, the space occupied by the voids may

vary from a minimum of one-fourth (26 per cent) to a maximum of one-half (48 per cent) of the total volume, depending upon the arrangement of the spheres but not on the size. If the spheres are of mixed sizes, the percentage of voids is of course reduced, the smaller spheres



(a) Sand (b) Clay

FIG. 12. Formation of Sand and Clay Deposits

progressively filling in the voids in the larger spheres. The ratio, expressed as a percentage, of the volume of voids in a soil to the total volume is called the *percentage of voids*, while the ratio of the volume of voids to the volume of the solid particles is called the *void ratio.* The percentages of voids, and therefore the void ratios, of sands are relatively small, whereas those of clays are large as is shown below:

PERCENTAGES OF VOIDS AND VOID RATIOS

	Percentage of Voids	Void Ratios
Sands	25 to 45	0.33 to 0.82
Clays	25 to 95	0.33 to 19.00

From this table it is seen that in sand the volume occupied by the voids is less than the volume occupied by the solids, but in extreme cases the volume of the voids in clay may be many times the volume of the solids. The voids of sand will be filled chiefly with air if the sand is above the ground-water level and mostly with water if below the ground-water level, while, except near the surface, the voids in most natural deposits of clays are filled with water regardless of the location of the ground-water level. Artificial clay fills may contain considerable *trapped air.* Sometimes gases other than air exist in the voids of clay. Occasionally these are inflammable and, with air, form explosive mixtures. Clay and silts in nature do not contain a measurable amount of air if they are below the zone of temporary desiccation.[20]

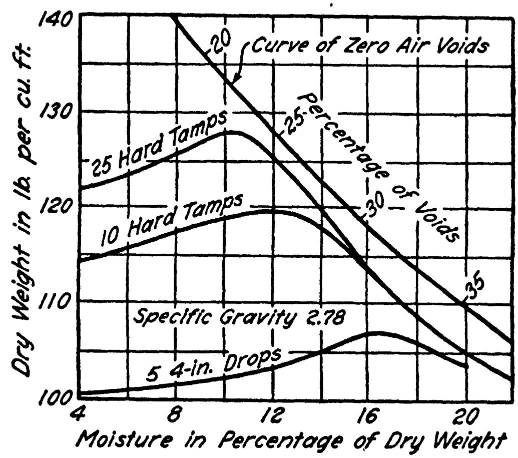
Permeability. An important property of any soil is its *permeability* or its ability to permit water to pass through its voids or pores. Because of their large grain size, the pore spaces between the grains of sand are large and offer relatively little resistance to the passage of water. In contrast to sand, the grains of clay are very small and the pore spaces, although usually much greater in total volume for a given volume of soil, are extremely small and offer great resistance to the passage of water. Sand, therefore, is very permeable and clay is very impermeable while silts are intermediate in permeability. However, there may be great differences in the permeability of different clays and the presence of a small amount of clay may greatly affect the permeability of a sand. Some clays are 1000 times as permeable as others, and "the addition of 10 per cent of bentonite to a quartz sand may reduce the permeability of the sand about 10,000 times."[21] As will be explained later, the permeability of a soil has a marked effect on the rate at which it compresses or consolidates under foundation loads and also on the water-tightness of the foundations of earth dams or on the water-tightness of the dams themselves.

Soil Water. Water may exist in soils in four states, i.e., capillary water, gravitational water, hygroscopic water, and adsorbed water. *Capillary water* is that contained in the minute pores which are so small as to cause capillary action to take place and is considered in the following paragraph. Water which flows through soil and which can be drained or pumped out is called *gravitational water.* Water which surrounds the individual grains with a thin film which can not be removed by air drying is called *hygroscopic* or *film water.* It can be removed by oven drying. *Adsorbed water* is that which clings to the surface of the soil grains and can not be removed by drying. The soil grains themselves do not absorb water but may contain *chemically combined* water. The ratio of the weight of the water, in a given quantity of soil, to the dry weight of the soil, expressed in per cent, is the *moisture content.*

The water contained in the voids or pores of soil is often called *pore water* and the pressure which exists in this water is referred to as *pore pressure.* This pore pressure resists external pressures which tend to compress or consolidate the soil and, by partially holding the soil grains apart, reduces the frictional resistance between grains and therefore reduces the shearing strength. For this reason, tests of the shearing strength of a given soil which do not take into account the pore pressure are of no value. Since sand is very permeable, the pore pressure in sand equals the hydrostatic pressure caused by the head of water above the point at which the pressure is determined except when the water is flowing. Because clay is very impermeable, the pore pressure under

a loaded area may be much higher than that in the surrounding soil. This inequality is gradually reduced as the water is forced from the pores of the soil under the loaded area and equilibrium is approached. This may require hundreds of years.

The density or weight per cubic foot of clayey soil that is compacted in embankments is dependent on the amount of moisture it contains. For a given size of roller and for a given number of trips over a soil deposited in layers of a given thickness, there is a moisture content which will give the greatest density at the time of placement, as shown in Fig. 13. This is called the *optimum moisture content.*[22]



Paul Baumann

FIG. 13. Relation between Moisture Content and Dry Weight of Soil

Capillarity. When water and air are present in soil, a concave surface, called a *meniscus*, forms on the pore water where it comes in contact with the air. This is often called a film. The *surface tension* in these so-called films binds the grains together. This effect is illustrated by damp sand. Also, the pores of soils serve as capillary tubes which cause water to be present in soils above the ground-water level. The *capillary rise*, or the height above the water surface to which water is raised by capillary action, varies inversely with the diameter of the tube or, in soils, with the diameter of the pores which is, in turn, a function of the grain size. The grain size of sand is so large that this soil possesses practically no capillarity; but the capillary rise in clays, with the small grain size, is very great. For this reason, the pores of clay are usually filled with water even though the ground-water level is many feet below, except in soil near the surface which has partially dried out. The rate at which capillary water is transmitted depends

upon the size of the pores; it is very slow in clay. Capillary water can not be drained out of soil by any system of drainage.

Volume Change. The volume of soils tends to change as the moisture content changes even though there is no change in the external load to which it is subjected. This *volume change* may be an increase in volume called *swelling* or a decrease called *shrinking.* The change in volume is brought about by stresses set up by capillary action in the pores of a soil which may be considered as bundles or networks of irregularly shaped capillary tubes running in all directions through the soil. At each point that a pore is exposed to air, a concave curved surface called a *meniscus* forms on the water in the pore and over the end of the pore. As water evaporates across this surface from the soil to

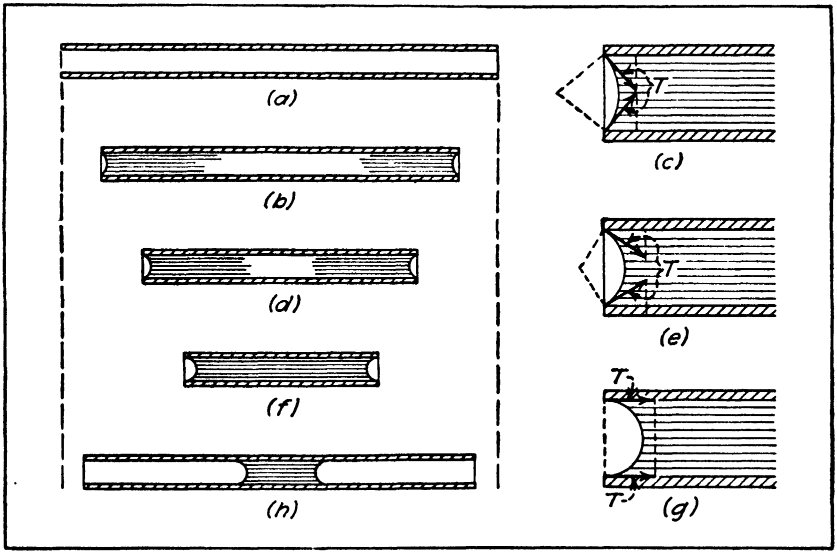


FIG. 14. Shortening of Tube due to Capillary Action (Greatly Exaggerated)

the air, the volume of the water in the pore decreases but the menisci remain at or near the ends of the pore. This action, in all the pores, results in a pulling together, compressing, or *shrinking* of the soil. If menisci come in contact with water, because of rains, flooding or other causes, they are destroyed and *swelling* occurs. There is a limit to the amount of shrinkage which can take place. The moisture content below which no volume decrease occurs and above which the volume increases is called the *shrinkage limit.* The pore size of sands is so great that no volume change occurs due to this capillary effect; but in clays this phenomenon is very pronounced, as evidenced by the deep cracks

which form in clay deposits as they dry out and disappear after rains.

The action which causes clay to shrink as it dries out can be compared with the changes which take place in an elastic tube, as illustrated in Fig. 14. These changes are greatly exaggerated in the figure for purposes of illustration. A tube of small diameter is shown in *a*. This tube is nearly filled with water, as shown in *b*. A curved surface called a *meniscus* is formed at each end, shown enlarged in *c*. There is *surface tension* at each meniscus which exerts a pull, *T*, around the perimeter of the end of the tube. This is a constant force for each unit of length of the perimeter and exerts a compressive force, *C*, on the tube, causing the tube to shorten, as shown in the figure. As the volume of the water decreases, as shown in *d*, owing to evaporation of water across the meniscus, the radius of curvature of each meniscus decreases, as shown enlarged in *c*; and the angle which *T* makes with the walls of the tube decreases. Since the magnitude of *T* remains constant, *C* increases and the tube is shortened. This action continues, as shown in *f*, until the menisci become tangent to the walls of the tube, as shown enlarged in *g*. The magnitude of *C* now equals *T*, its maximum value has been reached, and the tube has reached its minimum length. Further decrease in the volume of the water, owing to evaporation, causes the meniscus to recede into the tube, as shown in *h*. The tube increases in length because only a portion of the length of the tube is now compressed under the action of the meniscus. If all the water is evaporated or if the menisci are destroyed by flooding, the tube will return to its original length (*a*). Because of the complexity of the network of voids in soil, the action which takes place in soil is much more complicated than that which has been explained, but the basic causes of shrinking and swelling are the same. Soil does not expand to its original dimensions, as the tube does, when all of the water is evaporated. In soil, menisci form whereever there is air in the voids as well as at exposed surfaces.

Shearing Strength. The *shearing strength* of soils depends upon the friction between the soil grains, called *internal friction,* and upon *cohesion,* which is due partly to the molecular attraction of the grains of the soil for each other, called *true cohesion,* and partly to the binding of the soil mass together by the capillary action of the water in the pores of the soil, as explained in a preceding paragraph. The latter part of the cohesive strength is called *apparent cohesion.* Molecular attraction between two bodies varies directly as the product of the masses of the bodies and inversely as the squares of the distances between their centers of gravity. Because of the size of sand grains, the distance between their centers of gravity is so large that the molecular attraction is negligible in proportion to the number of grains; but the grain size of clay

is so small, the grains so flat, and the number of grains in a given volume so large, that molecular attraction is a factor in the cohesive strength. Also, because of the large size and the correspondingly large pores of sand grains, the capillary action in sand is small, while in clay, with its small grains and pores, it is very important. Therefore, the shearing resistance of sand is due to internal friction and that of clay to both internal friction and cohesion. If clay is submerged and capillary action destroyed, apparent cohesion disappears. Submerging has little effect on internal friction in sand. There are many difficulties in connection with determining the shearing resistance of clay but these will not be discussed here. As yet, the adaptation of shear test results to practical problems is not well understood.

Compressibility. The magnitude of the settlement of a foundation depends to a large extent on the *compressibility* of the soil on which it rests. For the unit pressures encountered in the soil under foundations, the unit stresses in the soil grains are relatively low considering the materials of which the soil grains are composed. The amount of compressive deformation in the grains themselves is negligible. The compressibility of a soil is therefore due to the decrease in the volume of the voids. For sands, with their bulky grains, there can be relatively little decrease in the voids unless the grains are rearranged by a sudden shock or by vibration. For clays, with their scalelike grains and large percentages of voids, the decrease in the volume of voids due to foundation pressures may be large. The compressibility of sand is therefore quite low, while for clays it is high and in some clays, such as those encountered in Mexico City, with void ratios as high as 14, it is very large. If the voids are filled with water, a part of this water must be squeezed out to permit the voids to decrease in volume because the compressibility of water is negligible for the pressures encountered in foundations. Because of its permeability, sand offers little resistance to the passage of water, and the final degree of compression is reached almost as soon as the load is applied even though the pores may be filled with water. On the other hand, clay is quite impermeable and the pores of natural deposits are normally filled with water so that compression takes place very slowly and continues over a long period of time. Air is forced out of the voids of sand almost instantaneously as pressure is applied and offers no resistance to compression. Air trapped with the water in the pores of clay, especially in artificial fills, may remain in place for a considerable period but compresses as soon as pressure is applied so that a certain amount of compression can occur instantaneously in clay if air is present in the voids. The process of squeezing water out of soil and thereby decreasing its volume is called *con-*

solidation. Consolidation can take place only when the stresses are large enough to break the bond between the soil particles.

Elasticity and Plasticity. When a body is stressed, its dimensions change. If, when the stresses are released, the body returns to its original form and dimensions, it is said to be elastic or to possess the property of *elasticity.* Sands are not elastic but clays may have considerable *elasticity* when the stresses are small in comparison with rupture values.

The capacity of a soil to undergo rapid changes in shape or flow when subjected to steady forces without a noticeable change in volume is called *plasticity.* Sands are not plastic but clays are plastic when the stresses are high.

Solubility. The proportion of soluble materials which exist in a soil is of importance in determining its suitability for the foundation of a dam or for constructing an embankment to serve as a dam. This is not a factor, however, in soil which is to serve to support the foundations of buildings. The most soluble material which may be found in soil is gypsum while limestone is slowly soluble.

Contrasting Properties of Sand and Clay. Sand and clay represent the two extremes, so far as the properties which are of interest to the engineers are concerned. This is shown by the following table which was prepared from a similar one by H. S. Gillette.[23] It must be kept in mind that sands and especially clays vary widely in their compositions and properties but that they possess certain general characteristics, such as those which have been mentioned, but to varying degrees.

CONTRASTING PROPERTIES OF SAND AND CLAY

Property	Sand	Clay
Grain size	Large and bulky	Minute and scaly
Pore size	Large and wide	Small and narrow
Void ratio	Relatively small	Usually high
Internal friction	Large	Very small*
Cohesion	Small	Usually large
Capillary effects	Very small	Very large
Permeability	High	Low
Compressibility	Low	High
Shrinkage	Very low	High
Elasticity	Low	High for low stresses
Plasticity	None	High for high stresses

*Internal friction of clay is large when no pore water is present. Pore water is usually present and holds the grains apart causing the "apparent" internal friction to be low.

Other Types of Soil. The discussions in this article have been confined to sands and clays for the sake of simplicity and to avoid con-

fusion. Other soils and other names applied to soils will be considered briefly.

Silt is intermediate in properties to fine sand and clay.

Gravel consists of rounded particles over 2 mm. or $\frac{1}{12}$ in. in diameter. It is composed chiefly of quartz but may contain granite, limestone, basalt, and other rocks. The lower limit of the size of gravel grains is sometimes taken as $\frac{1}{4}$ in.

Pebbles are the smaller constituents of gravel with diameters up to 2 or 3 in.

Boulders are the larger constituents of gravel or may be very large, rounded blocks of rock many feet in diameter.

Loam consists of various mixtures of sand and clay usually containing organic matter.

Marl is a mixture of quartz, clay, and calcium carbonate.

Gumbo is a dark-colored, sticky clay.

Adobe is a sandy, calcareous clay.

Bentonite is a clay formed by the weathering of volcanic ash. It increases in volume very markedly when water is added and shrinks correspondingly when dried. Its void ratio is very high.

Loess is a light-colored silt or silty clay transported and deposited by wind.

Quicksand is any finely divided sand subjected to the lifting action of water flowing upward through its mass so as to counteract the downward effect of the weight of the particles and thus cause it to behave as a liquid.

Peat is a highly fibrous organic material with easily recognizable plant remains. It compresses to a large degree when subjected to pressure.

Muck is primarily decomposed black organic material with a considerable amount of finely divided mineral soil and a few fibrous remains.

Rock flour is finely divided rock particles, similar to silt, ground off the surface of bed rock by glacial action.

Structural Uses of Soils. Soil is an important structural material. In its natural position, it serves as the support for the foundations of most structures, only the foundations for some of the major structures being carried to rock unless rock is readily accessible. Valleys in natural soil deposits serve as reservoir sites, and canals excavated in earth are used to convey water for various purposes.

Embankments constructed of soil, which in this usage is more commonly called earth, serve to support highways and railways and to retain water as dams. When used for these purposes the soil is excavated, transported to its position in the structure, and compacted.

Clay is used as the sole or principal material in the manufacture of brick, hollow tile, terra cotta, roofing tile, floor and wall tile, sewer pipe, farm tile drains, porcelain plumbing fixtures, and in many other ways in connection with structures. The clay is selected for the particular

purpose for which it is to be used and is transformed into the finished product primarily by the application of heat.

Clay is one of the principal ingredients of portland cement. When used for this purpose, it is mixed with the proper amount of limestone, pulverized, burned to a clinker, and pulverized again.

Sand is an essential ingredient in mortar used in laying brick, stone, and other masonry units; in plaster and stucco. When used for these purposes, it is mixed with water and with some cementing material such as portland cement, lime, or gypsum plaster.

Probably the most important structural use of sand is as one of the four principal ingredients of concrete, the others being portland cement, gravel or crushed stone, and water.

Sand and gravel are used where a free-draining material is required, as under concrete floor and pavement slabs and as a surface for dirt roads. Sand is used as a cushion under brick floors and pavements to secure an even bearing. Sand is one of the principal ingredients of window and structural glass.

REFERENCES

1. CAMP, J. M., and C. B. FRANCIS: "The Making, Shaping, and Treating of Steel," Carnegie Steel Company, 1919, Revised Edition, 1940.

2. MILLS, ADELBERT P. (the late), HARRISON W. HAYWARD (the late), and LLOYD F. RADER: "Materials of Construction," 5th Ed., John Wiley & Sons, 1939.

3. MURPHY, GLENN: "Properties of Engineering Materials," International Textbook Co., 1939.

4. MOORE, HERBERT F.: McGraw-Hill Book Co., 5th Ed., 1936.

5. U. S. DEPARTMENT OF COMMERCE: "American Lumber Standards for Soft Wood Lumber," Simplified Practice Recommendations, R16–39, 1939.

6. FOREST PRODUCTS LABORATORY: "Wood Handbook," U. S. Department of Agriculture, 1935.

7. HOLTMAN, DUDLEY F.: "Wood Construction," McGraw-Hill Book Co., 1929.

8. PORTLAND CEMENT ASSOCIATION: "Design and Control of Concrete Mixtures," 1940.

9. U. S. BUREAU OF RECLAMATION: "Concrete Manual."

10. Report of Joint Committee: "Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete," American Society of Civil Engineers, American Society for Testing Materials, Portland Cement Association, American Concrete Institute, American Railway Engineering Association, American Institute of Architects, 1940.

11. FOX, CYRIL: "Engineering Geology," D. Van Nostrand Co., 1935.

12. MEAD, WARREN J.: "Geology of Dam Sites in Shale and Earth," *Civil Engineering*, June, 1937.

13. KESSLER, D. W., and W. H. SLIGH: "Physical Properties of Limestone in the United States," Technologic Paper 349, U. S. Bureau of Standards.

14. LEGGETT, R. F.: "Geology and Engineering," McGraw-Hill Book Co., 1939.

15. BOWLES, ALVIN: "The Stone Industries," McGraw-Hill Book Co., 1939.

16. RIES, H., and T. L. WATSON (the late): "Engineering Geology," 5th Ed., John Wiley & Sons, 1936.

17. HOGENTOGLER, C. A., and C. A. HOGENTOGLER, JR.: "Engineering Properties of Soils," McGraw-Hill Book Co., 1937.

18. PLUMMER, FRED L., and STANLEY M. DORE: "Soil Mechanics and Foundations," Pitman Publishing Corp., 1938.

19. CASAGRANDE, A.: "The Structure of Clay and Its Importance in Foundation Engineering," *Journal of the Boston Society of Civil Engineers,* April, 1932.

20. TERZAGHI, CHARLES: "The Science of Foundations," *Transactions of the American Society of Civil Engineers,* No. 93, 1929.

21. GRIM, R. E.: "The Clay Minerals in Soils and Their Significance," *Proceedings of the Purdue Soil Mechanics Conference,* 1940.

22. PROCTOR, R. R.: "Fundamental Principles of Soil Composition," *Engineering News-Record,* Vol. 111, 1933.

23. GILLETTE, H. S.: "Elementary Soil Fundamentals," University of Oklahoma Press, 1936.

24. TERZAGHI, CHARLES: "Physical Differences Between Sand and Clay," *Engineering News-Record,* Dec. 3, 1925.

25. KRYNINE, DIMITRI P.: "Soil Mechanics," McGraw-Hill Book Co., 1941.

26. MCNAUGHTON, G. C.: "Fire-Retardant Treatments for Wood," *Quarterly of Fire Protection Association,* January, 1943.

27. MARKWARDT, L. J.: "Wood as an Engineering Material," *Proceedings of the American Society for Testing Materials,* Vol. 43, 1943.

CHAPTER III

FOUNDATIONS

ARTICLE 13. DEFINITIONS AND GENERAL DISCUSSION

Definitions. The part of a building below the surface of the ground is often called the foundation or *substructure,* and that above the ground, the *superstructure.* The soil or rock on which a building rests may also be called the foundation, and its surface, the *foundation bed.* In this book, the part of a building which bears directly on, and transmits the building load to, the supporting soil or rock is called the *foundation,* whereas the rock or soil is called the *foundation material.* Walls below the surface of the ground and resting on the foundations are called *foundation walls.*

The terms *bearing power, bearing capacity,* and *bearing value* are used to designate the ability of a soil to support safely foundation loads without excessive settlement or danger of rupture of the soil. The minimum load which will cause failure of a foundation by actual rupture of the soil is called the *ultimate bearing power,* the *ultimate bearing capacity* or the *ultimate bearing value.* All of these values are commonly expressed in pounds or tons per square foot of bearing surface.

Variations in Foundation Materials. As stated in Art. 11, the upper portion of the earth's surface consists of solid rock, called *bed rock,* overlaid with unconsolidated material called *soil,* which has been derived from rock. Foundations may be supported on soil or they may be carried to bed rock, depending on conditions. Bed rock may be exposed on the surface or it may be several hundred feet deep. Rock is not solid over large areas but is broken up into relatively small units by joints, bedding planes, faults, and other structural features. It may also contain caverns and solution channels. Bedding planes may be horizontal, as originally formed, or inclined. Marked variations in kind and properties of rock may occur within short distances or at different depths. Soils are also subject to wide variations in general type and in physical properties. A soil with high bearing power may be underlaid with one whose bearing power is low. Layers of peat, which deforms greatly under load, may cause excessive settlement if not discovered and provided for.

The formation, the composition, and the properties of rock and soil are discussed in Arts. 11 and 12 and should be kept in mind when reading this chapter.

Ground Water. A large portion of the land surface of the earth is underlaid with *ground water* which occupies the pores and other open spaces in the soil and rock. This water flows in the same manner as surface water. Its surface is called the *ground-water table* or, simply, the *water table.* The ground-water table usually is not horizontal but follows, in a general way, the contour of the ground surface. The elevation of the ground-water table at a given point is called the *ground-water level.* Reference is often made to the *permanent ground-water level,* but it should be understood that there is no permanent ground-water level in most locations. The elevation of the water table varies with the amount of rainfall and with the amount of pumping for water supply or for other purposes and may be lowered by the construction of sewers, drains, subways, and other underground works, and by covering the surface with pavements and buildings.

The location of the ground-water table is of particular importance in selecting the type of foundation and in planning construction procedures, even though it is below the lowest basement floor and is not a factor in the design of the basement walls.

Subsurface Exploration. Because of uncertainties which exist concerning underground conditions, adequate subsurface explorations should be made before the foundations of buildings are designed or possibly, in some cases, before a site is purchased. Methods for making such exploration are described briefly in Art. 14.

Types of Foundations. Building loads may be transmitted to the earth in the following ways:

a. By *spread foundations* bearing on soil over a sufficient area so that undue settlement does not occur. Foundations of this type may consist of individual *footings* under walls or columns, as shown in Fig. 15*a*. Or a single, heavy, reinforced concrete slab called a *mat* or *raft* may cover the entire area of the foundation and support all the building loads, as shown in Fig. 15*b*. Foundations of the latter type are often called *floating foundations,* although this term is commonly applied to all types of spread foundations.

b. By *pile foundations* in which the load is distributed into the soil by slender, vertical members of timber, concrete, or steel, called *piles,* or is transmitted directly to hardpan or rock by piles which pass through soil, with little or no bearing power, until their lower ends bear on the hardpan or rock. Foundations of this type may consist of individual footings called *pile footings,* under walls and columns, as

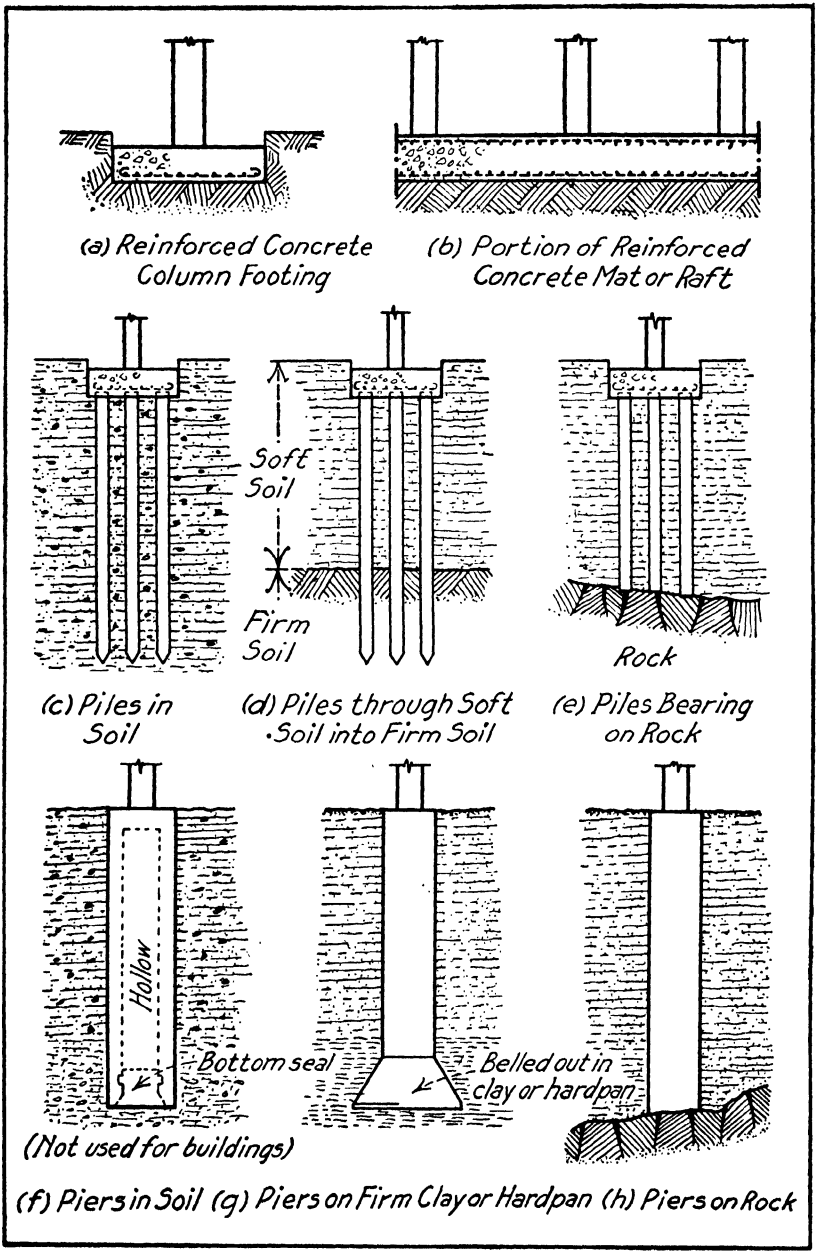


FIG. 15. General Types of Foundations

shown in Figs. 15*c* to *e*, supported on groups of piles or may consist of a single member called a *mat* or *raft*, as in spread footings, with more or less uniformly spaced piles under the mat.

c. By *pier foundations* in which concrete piers are carried down through soil of inadequate bearing power until a satisfactory foundation bed is reached. This may be firm clay, in which case the pier is usually *belled out* at the base, as shown in Fig. 15*g*, to increase the bearing area; it may be hardpan which usually requires that the piers be belled out, as shown in Fig. 15*g*; or it may be rock, as illustrated in Fig. 15*h*.

If the character of the soil is such that belling out is not possible or if the dimensions of the superstructure determine the dimensions of a pier, as may be true with bridge piers, piers may be made hollow, as shown in Fig. 15*f*. Such piers are not used for buildings.

The choice of type of foundation depends upon many factors which are discussed in subsequent paragraphs.

Minimum Depths. The depth to which foundations must be carried depends upon the space requirements of the building, the depth of adjacent foundations, the loads which must be carried, the character of the foundation material, and climatic conditions. Except where bearing on solid rock, foundations which may be exposed to freezing temperatures must be carried below the *frost line* in order to prevent heaving due to frost action.[20] A minimum depth of 1 ft. below the frost line is commonly specified. The depth to the frost line, which is the maximum depth to which the ground freezes, varies with the locality. In the northern parts of this country, the frost line may be as low as 6 ft. below the surface, whereas, in parts of the South, the ground never freezes. In most cities, the depth to the frost line is fairly well established by the depth at which water mains must be placed to prevent freezing.

Subsurface explorations, as described in Art. 14, should be carried a sufficient depth into soil to insure that there are no layers of low bearing power underlying the site which will cause excessive settlement of spread or pile foundations and that no cavities or weak areas exist under piers founded on rock. Layers of peat below the points of piles have caused excessive settlement of pile foundations.

Excavations Affecting Adjoining Property. In excavating for the basement and the foundations of a new building, it is very often necessary to make some provision to prevent the adjoining land from suffering damage by the caving of the banks and to prevent injury to the buildings on adjoining land due to disturbing or undermining of the foundations. This may require that the foundations of such buildings be extended to greater depths.

At common law, the owner of a piece of land has the right to the lateral support of his land. If the lateral support is removed by excavating on the adjacent property some other provision for lateral support must be made by the person responsible for the excavation. This right of lateral support relates only to the land in its natural condition and it does not include provisions which must be made to protect the buildings on the land. The proper division of the responsibility when buildings as well as the land itself must be supported is not a simple matter. To fix such responsibility more definitely, the building codes of cities usually contain specific clauses concerning this matter. These clauses, if their legality is established, take precedence over the provisions of common law.

In many cities, if the depth of the excavation is not greater than a specified depth, the owners of adjacent buildings must take the necessary steps to protect these buildings. If the excavation extends beyond this depth, however, the persons causing the excavation to be made must assume responsibility for such protection unless the owners of the adjacent property refuse them the right of entering on their property to carry on this work. If the excavations are not to be carried below the specified depth, the persons responsible for the excavations are required by the codes of some cities to protect the excavation so that the adjoining soil will not cave or settle, even though they may not be required to make necessary extensions in foundations. If excavations are to be carried below the specified depth, many cities require that the owners of the adjoining buildings extend their foundations to the specified depth, but the person responsible for the excavation must extend these foundations the necessary amount below that depth. This specified depth varies in different cities from 10 to 14 ft. below the street grade or elevation of the curb.

Some other cities require that the persons who cause the excavation to be made must be responsible for all necessary protection of adjoining land and buildings regardless of the depth of the excavation. At least one city has taken the opposite position and makes it the duty of the adjoining property owners to protect their own buildings from damage due to excavations.

Considering the varying practice concerning the responsibility for the protection of adjacent property, a careful investigation of the local requirements should be made before preparing an estimate for a proposed building and before starting building operations.[1] Much litigation originates in controversies over the responsibility for the cost of protecting the foundations of adjacent buildings.

ARTICLE 14. SUBSURFACE EXPLORATION

General Discussion. Before a building site is purchased, or at least before the foundation plans are prepared, an investigation should be made to determine the character of the underlying material which will be called upon to support the building and the depth to the ground-water table. Even where ground water does not affect the design of a building, it may have an important effect on the cost because of construction difficulties. With important structures on questionable soil, it is desirable to estimate the amount of settlement of foundations which may be expected, and the possibility of swelling of the soil should be investigated also. When settlement predictions are made, it is necessary to secure samples of the soil at various depths below the bottoms of the foundation. In taking such samples it is desirable, if possible, to keep them in their natural, undisturbed state. They are called *undisturbed samples.* Various devices have been developed to secure such samples but all devices cause some disturbance and none is entirely satisfactory.

Loading tests may be made to determine the bearing power of the soil, but, before reaching a decision to make such tests, the possibility of their being of any value should be considered. As is explained in Art. 17, such tests may be of little or no value because the bearing power of some soils does not vary in direct proportion with the area, and the soil a few feet below the elevation of the test area may be of a very different character from that contributing to the test results. In a loading test over a small area, usually 1 ft. square, only the soil for a short distance below the loaded area carries sufficiently high stress to affect the results, whereas the character of the soil for a considerable depth below an actual foundation contributes to the settlement of the foundations, as explained in Art. 17. The larger the foundation, the greater the depth which affects the results. This depth is usually about 1½ times the width of the foundation.[19]

Methods of Subsurface Exploration. Various methods are used in determining the character of the material underlying a building site. The usual methods may be listed as follows:

a. Test pits.
b. Sounding rods.
c. Soil augur boring.
d. Wash boring.
e. Churn drilling.
f. Diamond drilling.
g. Shot drilling.
h. Geophysical methods.

The methods listed from *a* to *e*, inclusive, are appropriate for soils, while *a*, and *e* to *g*, inclusive, are used in rock. Since buildings are founded on soil or on the surface of bed rock, it is only necessary to

drill into bed rock, and then only far enough to insure that the solid rock encountered is thick enough to carry the proposed load. Methods *d* and *e* are used to penetrate boulders encountered in soil. Method *a* can be used in rock, but the information necessary for examining rock for building foundations can be secured more cheaply by other methods. Geophysical methods, as listed under *h*, make use of variations in the properties of various rock and soil formations to transmit sound or electricity in predicting the subsurface conditions. They are not used in the investigation of building sites and so will not be considered further. Each of these methods, except the geophysical methods, will be explained briefly.

Test Pits. The most satisfactory method for securing reliable information concerning subsurface conditions in soil is by means of *test pits,* for this method permits the examination of the soil in its natural, undisturbed state. However, this method is relatively expensive. The pits must be large enough for a man to work in. They are shored to prevent caving and, in loose soil, must be lined. This may be accomplished by horizontal or vertical timbers properly supported.

Sounding Rod. The *sounding rod* consists of a steel rod or pipe about ¾ in. in diameter, arranged in lengths of about 5 ft., joined by standard couplings, and provided with a point at the lower end. This is driven by hand into soil with a maul or drop weight, lubricated with water if necessary, and turned with a pipe wrench to reduce the tendency to stick. Some idea of the nature of the soil is obtained from the number of blows required to drive the rod. Driving should continue until the rod "refuses" to penetrate further. This may mean that rock has been struck, particularly if the rod "brings up" with a sharp ring. The effect is the same if a large boulder is encountered and therefore other probings should be made nearby to see if rock is encountered at about the same elevation, otherwise the progress of rod may have been stopped by a boulder. After driving has been completed, the rod is pulled by means of a lever and chain or by some other device. This method, of course, yields no samples of the soil penetrated, but experienced operators may be able to judge the soil at various depths by the way the rod drives. At any rate, the results secured are of little value except for determining the depth to rock if it is within reach of the rod.

Soil Augur Boring. Holes may be bored into soil with *soil augurs* rotated by hand, horsepower, or gasoline engines. The augurs are of various types, depending upon the material to be penetrated and upon the kind of power used. They vary in diameter from 1½ to 24 in., the smaller sizes being suitable for investigating soil for the foundations of

buildings. They are mounted on sections of pipe, new sections being added as the boring progresses. If the material being penetrated is damp sand or if it contains considerable clay, the hole may not cave but, if caving occurs, the augur is operated inside a metal casing which may go down easily as the boring progresses or may have to be driven. If the soil being penetrated will adhere to the augur, a fairly good idea of its nature can be obtained from examining this soil. Below the ground-water level, in sand or silt, it may be necessary to use a bailer to remove the soil, and sometimes this device has to be used above the ground-water level by adding water to the hole and mixing it with the soil which is to be removed. If boulders are encountered, they are drilled with a churn drill or are shot with explosive charges.

Wash Boring. The most common method for boring test holes into unconsolidated materials is *wash boring.* This method is also used for penetrating boulders and rock. In this method, a bit is mounted on the lower end of a pipe, called a *drill rod,* through which water is forced. The drill rod is worked up and down or churned in the hole and rotated slowly. The bit strikes the soil or rock at the bottom of the hole and gradually penetrates it. The bits used are of various types, depending upon the material to be penetrated, but in every instance they are provided with holes which permit the water to pass from the drill rod through the bit and against the sides of the hole. The width of the bit is greater than the diameter of the drill rod to provide clearance. The cuttings are washed to the surface by the water's rising in the annular space between the rod and the sides of the hole. This operation gives the process its name. In soil, the drill is removed and a casing is installed before a depth is reached at which caving occurs. The casing is driven down at intervals as the drilling progresses. The nature of the soil penetrated is often judged by examining the borings or cuttings which are brought to the surface by the wash water but such information is very unreliable. Experienced operators may be able to form some estimate of the character of the soil being penetrated by the " feel " of the equipment. A more satisfactory way to determine the character of the soil consists of removing the bit and the drill rod from the hole and replacing the bit with an open-ended pipe. The apparatus is again placed in the hole and the pipe is driven into the soil at the bottom of the hole. The pipe is brought to the surface and the sample is removed and examined. It is called a *dry sample* to distinguish it from the samples brought up in the wash water, but it is not dry. Such a sampling procedure is, of course, not adaptable to rock. This boring method is used for penetrating sand, gravel, clay, boulders, and solid rock.

Churn Drilling. The *churn-drilling* or *dry churn-drilling* method is similar to the wash-boring method, just described, with the exception of the means for removing the cuttings. In removing the cuttings, only enough water is used to fill the bottom portion of the hole. The cuttings become mixed with this water as the churning proceeds and at intervals the drill stem is withdrawn, the cuttings and water being removed by means of a sand pump or bailer which is lowered into the hole. The samples are usually obtained from the bailer and are very unreliable indicators of the material penetrated. The method is used in soil, boulders, and rock. If reliable soil samples are required, they may be obtained the same as " dry samples " in the wash-boring method; or core samples of rock may be secured at intervals with diamond drills, shot drills or saw-toothed drills, as described in the subsequent paragraphs, the churn-drill equipment being removed while the cores are being obtained.

Diamond Drilling. The *diamond drill,* which is only suitable for drilling in rock, consists of a steel cylinder with black diamonds set on the outside and on the inside edges of the bottom of the cylinder to form a bit. The diamonds are set to provide a small amount of clearance so that the hole bored will be slightly larger than the outside diameter of the drill cylinder and so that the outside diameter of the core will be slightly smaller than the inside diameter of the cylinder. The drill is rotated by applying some kind of power and cuts into the rock by abrasive action. Water is forced down the drill rod to the bottom of the hole and rises in the annular space between the drill rod and the sides of the hole. This water removes the cuttings and keeps the bit cool.

The bit is not attached directly to the drill rod, but a cylinder called a *core barrel* is placed between the two to provide space for length of core up to 10 ft. or so. The portion of core in the core barrel is removed at intervals by withdrawing the drilling apparatus. The *core lifter* automatically grips the core so that it is removed in the barrel. The core provides a more or less continuous record of the material penetrated. Gaps usually exist in the record because the recovery of cores is not often complete. This method is expensive but is rapid. The size of core is commonly 1⅛ in. and the size of hole is 2 in. Large holes can be drilled, but the cost increases rapidly with the diameter of the hole. The diamond drill can drill in any direction.

Shot Drilling. The *shot drill* is being used extensively to secure cores from rock. It consists of a cylindrical bit which is rotated by a drill rod, to which it is attached, and it cuts a circular groove in the rock. The cutting action is provided by chilled steel shot which are fed

into the hole from above and find their way under the rotary bit. The cuttings are washed from the cutting surface by water which is pumped through the drill rod and bit to the bottom of the hole and which rises in the annular space between the drill rod and the sides of the hole. A core barrel is provided between the bit and the core rod, as in the diamond drill.

The drill rod is considerably smaller in diameter than the core barrel and the bit so that the velocity of flow of the water which rises upward in the annular space between the drilling apparatus and the sides of the hole is much less above the top of the core barrel than below. For this reason, the cuttings accumulate in a space provided on top of the core barrel and are removed when each section of core is withdrawn.

When cavities or open seams are encountered, progress is stopped because the shot disappear into the open spaces and do not remain in contact with the lower edge of the bit. At such times, the open spaces are filled with cement grout. After this sets, drilling is resumed, the bit cutting through the grout.

The size of hole is usually 4 or 5 in., but 36-in. holes have been extensively used in investigating dam sites and at times even larger holes have been drilled. The larger holes permit men to go down actually to examine the rock penetrated. Such thoroughness is not necessary for examining the rock under the foundations of buildings. The shot drill can only drill vertically downward.

Detailed information concerning methods of subsurface exploration is given in references 2 to 5 at the end of this chapter.

ARTICLE 15. TYPES OF SPREAD FOUNDATIONS

Definition and General Discussion. *Spread footings* include all those types which are designed to spread the building loads over a sufficient area of soil to secure adequate bearing capacity.

They may be divided into the following classes according to the manner in which they receive the loads:

a. A *wall footing,* as shown in Fig. 16*a*, *c*, and *e*, is one which supports a wall by extending along the entire length of the wall.

b. An *isolated* or *independent* footing, as shown in Figs. 16*b*, *d*, *f*, *g*, and *h*, is one which supports a single column, pier, or other concentrated load. One which supports a column is called a *column footing.*

c. A *combined footing,* as shown in Fig. 17*a*, *b*, and *c*, is one which supports two column loads or sometimes three column loads not in a row.

d. A *cantilever footing,* as shown in Figs. 17*e* and *f*, is one which supports two column loads and consists of two footings connected together by a beam,

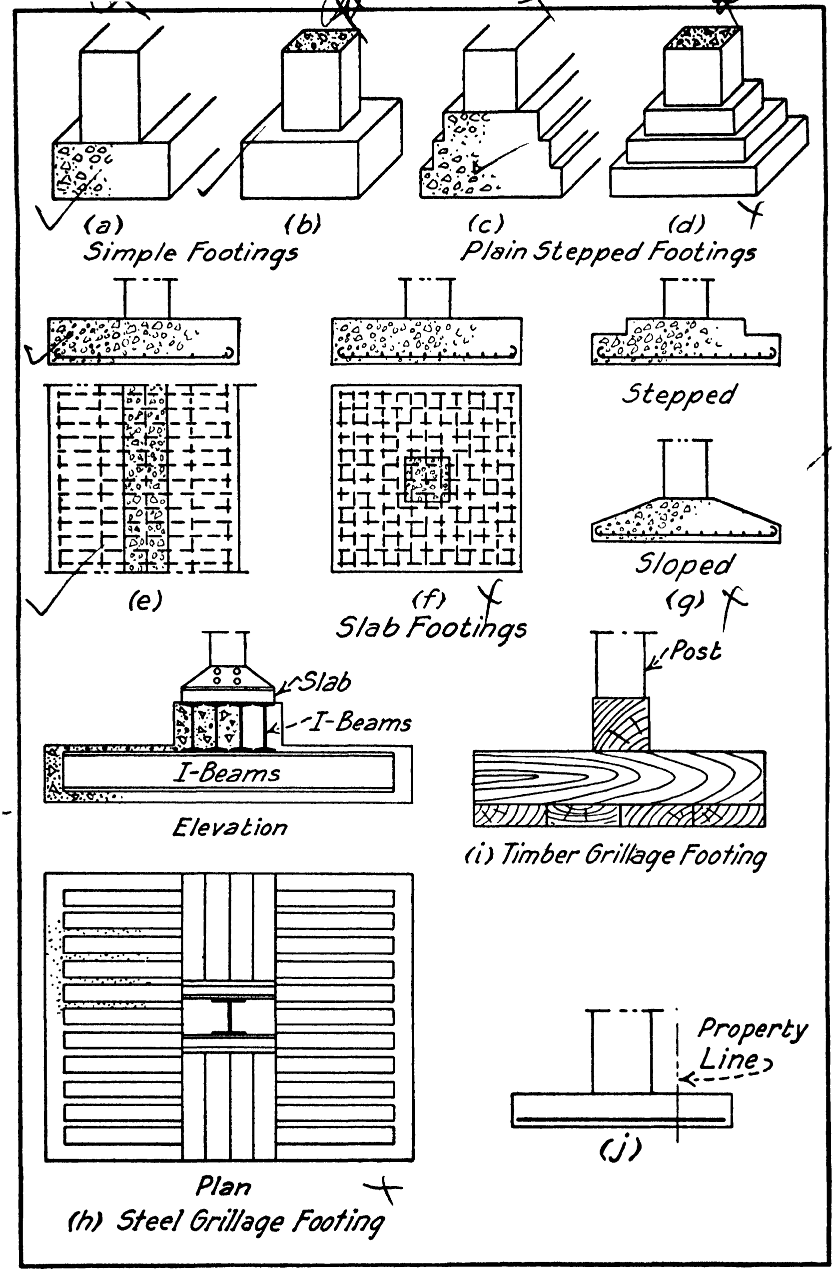


FIG. 16. Spread Footings

often called a *strap*, as explained more fully later. A footing of this type is sometimes called a *connected footing* or a *strap footing*.

e. A *continuous footing*, as shown in Fig. 17*g*, is one which supports a row of three or more columns. A *two-way continuous foundation* consists of continuous footings placed at right angles to each other, as shown in Fig. 18*a*.

f. A *raft* or *mat foundation* is one which extends under the entire building area and supports all the wall and column loads from the building, as shown in Fig. 18*b*, *c*, and *d*. It is often called a *floating foundation*, but this term is commonly applied to any spread foundation.

Spread foundations are divided into the following groups according to their structural characteristics:

a. A *simple footing* is one which projects only a few inches beyond the edges of a wall or column, as shown in Figs. 16*a* and *b*. Such footings are used only for light loads and the stresses in the materials are low.

b. A *stepped footing*, as shown in Figs. 16*c* and *d*, provides for a wider distribution of the load over the soil. It is made of brick and stone masonry and of plain concrete and was used extensively at one time. However, it has now been replaced largely by reinforced concrete slab footings.

c. A *slab footing* consists of a reinforced concrete slab supporting a wall, as shown in Fig. 16*e*; a single column, as in Figs. 16*f* and *g*; two columns, as in Figs. 17*a* and *c*; several columns, as in Figs. 17*g* and *h*; and all columns of a building as in Fig. 18.

d. A *grillage footing* is one in which the structural elements are tiers of parallel steel I-beams or timber beams, as shown in Figs. 16*h* and *i*, Figs. 17*b* and *e*.

Wall Footings. Wall footings may be simple footings constructed of plain concrete if the loads are light and do not require projection exceeding about 6 in. beyond the edges of the wall. The depth of such footings is commonly required to be equal to at least twice the projection. It is usually desirable to provide light, longitudinal reinforcement in simple concrete wall footings in order to distribute shrinkage and temperature cracks, so that they will not be objectionable, and to bridge over soft spots in the soil. Similar dimension requirements prevail for wall footings constructed of hard-burned brick and flat stones, but these materials are rarely used. Greater footing widths can be provided by unreinforced stepped footings, for which it is commonly required that the depth of each step must at least equal twice the width. Stepped footings are rarely used.

The most common type of wall footing is the reinforced concrete slab footing of constant depth, but occasionally the top surface of the footing is stepped to save concrete. However, the increased labor cost may offset this saving. If footings with steps are used, there is a

tendency to pour each step separately and allow the concrete to set, at least partially, between operations. This should not be permitted because, in design, it is assumed that the whole footing will act as a unit. The main reinforcement in a spread footing for a wall is perpendicular to the wall and near the bottom of the slab to keep the projections from cracking off near the wall lines. The reinforcing bars tend to slip in the concrete because of high bond stresses. This condition makes it necessary to obtain a large surface area on the reinforcing bars by using small, closely spaced bars rather than large bars spaced farther apart. Also, it is usually necessary to hook the ends of the bars to secure end anchorage and thereby to prevent slipping. Longitudinal reinforcement is provided for the reasons given under simple footings. Spread footings are more desirable than unreinforced stepped footings because the latter occupy more space in a basement, or if they are kept below the basement floor a greater amount of excavation and material is required. The weight of stepped footings is greater and therefore adds to the load on the soil. The saving in reinforcing steel by the use of stepped footings is partially or wholly offset by the increased cost of the concrete and form work.

Column Footings. Column footings are the most common type of isolated or independent footings. For light loads, they may be of the simple type, but most column footings are slab footings with two-way reinforcing, as shown in Fig. 16*f*, with constant depth. As is true of wall footings, small, closely spaced bars with hooked ends should be used to provide greater bond strength. The comments concerning stepped and sloping top surfaces made under wall footings apply to column footings also. Grillage footings may be constructed of tiers of timber beams, as shown in Fig. 16*i*. The upper beam or beams, whose end view shows in the figures, is placed under the column base and distributes the load to a tier of transverse beams. In the timber grillage footing, a layer of heavy planks is placed under the lower tier of beams to distribute the load to the soil. In the steel grillage footing, the beams are held in position by spacers placed between them, a layer of concrete 6 or 8 in. in thickness is placed under the lower beams and the entire footing is filled solidly with concrete and encased in concrete with a minimum thickness of 4 in. Timber grillage footings are only permitted for temporary buildings and for frame buildings when the footings are below the " permanent " groundwater level. Steel grillage footings have been largely replaced by reinforced concrete slab footings.

Combined Footings. Footings of this type are most frequently used to support wall columns which are close to the property line. If such a

column were centered on an isolated footing, as shown in Fig. 16*j*, the footing might project over the property line. If it were placed near the edge of such a footing, the foundation pressures would not be evenly distributed and the footing would tend to settle unevenly. This condition can be overcome by combining the wall column footing and the nearest interior footing into a single footing, as shown in Figs. 17*a*, *b* and *c*. Combined footings are so proportioned that the centroid of the area which bears on the soil is on the line of action of the resultant of the column loads, in order to avoid any tendency to rotate. This usually results in a trapezoidal footing. It is commonly assumed that this arrangement also produces uniform pressure distribution under the footing. However, as explained in Art. 16, this result is probably not effected. The footings for a wall column and two adjacent interior columns may be combined, and many other arrangements are made, particularly at the corners of buildings. Combined footings are usually constructed of reinforced concrete, as shown in Fig. 17*a*, but grillage footings, as shown in Fig. 17*b*, have been extensively used in the past. A combined footing may be rectangular in plan, as shown in Fig. 17*c*. If the interior column load is greater than the wall column load, a footing of this form can be so proportioned that the centroid will be on the line of action of the column loads, by adjusting the inward projection of the footing. The building codes of some cities permit foundations adjacent to streets and alleys to project over property lines. This greatly simplifies the foundation construction in such cases.

Cantilever Footings. Footings of this type are designed to serve the same function as combined footings by permitting a wall column load to be placed near the edge of a footing. The principle of the cantilever footing is illustrated in Fig. 17*d*. The load of the wall column is considered supported near the end of a beam which has one support over the center of the wall footing and the other support at the adjacent interior column. Since the beam projects beyond its support on the wall footing, it is said to "cantilever" beyond the support. Cantilever footings are usually made of reinforced concrete, as illustrated in Fig. 17*f*, but steel grillage footings of this type, as shown in Fig. 17*e*, have been used extensively in the past. The cantilever principle is not evident in actual footings, as illustrated in the figures, because in both types an actual fulcrum is not used and in the reinforced concrete footing the beam is merged into the slabs. However, it is evident that the beam prevents uneven settlement of the wall footing, due to the eccentric load, by holding it in a horizontal position. The beam connecting the footings is called a *strap beam*, and footings of this type are often called *connected footings*.

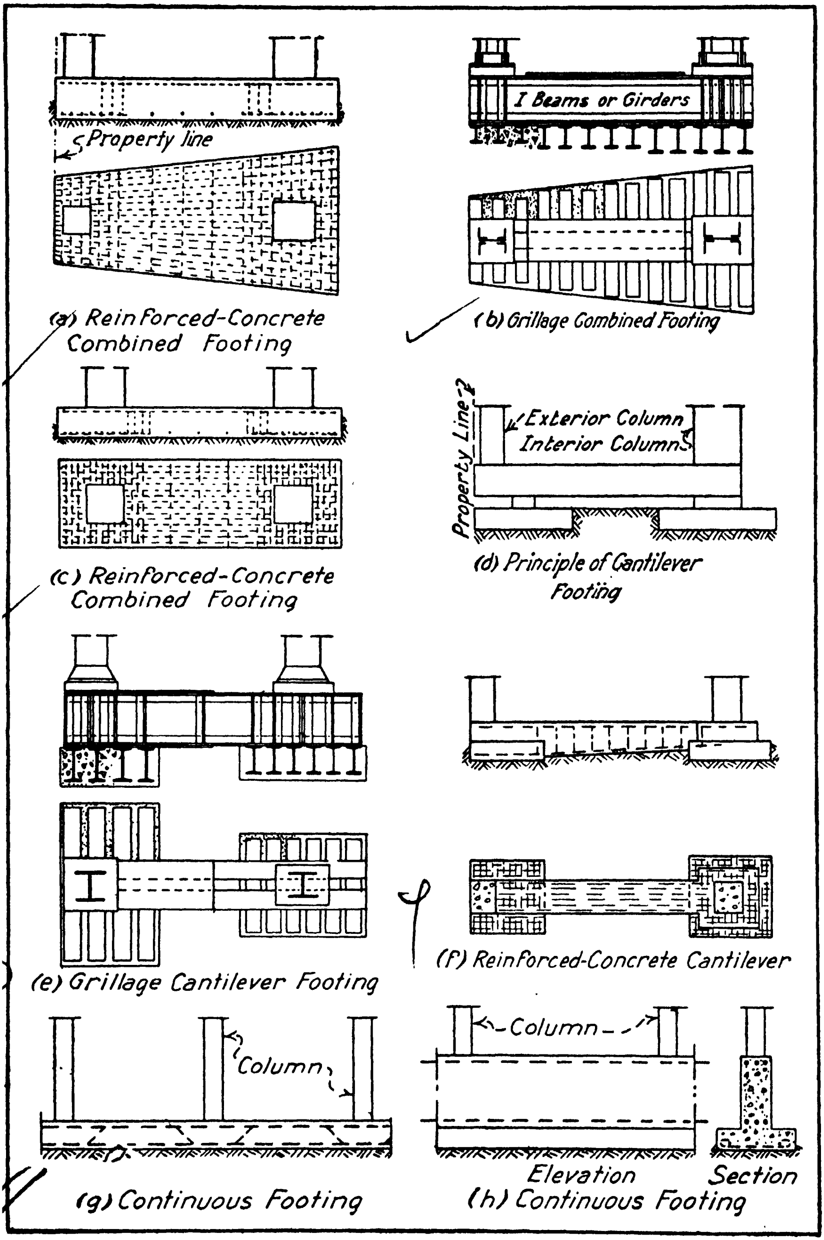


FIG. 17. Combined, Cantilever, and Continuous Footings

Continuous Footings. Continuous footings commonly consist of reinforced concrete slabs extending continuously under three or more columns, as shown in Fig. 17*g*. They tend to reduce the differential settlement between columns. This action is more effective if the foundation wall is constructed as a reinforced concrete girder, as shown in Fig. 17*h*. If the footing and the wall are poured separately, as is usually done, the lower reinforcing should be placed at the bottom of the wall, as shown in the figure, but if they are poured in one operation this steel is more effective if placed near the bottom of the footing. Transverse reinforcing must be provided near the bottom of the slab, as shown in Fig. 17*h*. Corresponding steel is required in the footing illustrated in Fig. 17*g*. Continuous foundations of the type shown in Fig. 17*h* may be used to support bearing walls as well as columns. This type of construction is very desirable because it reduces differential settlement due to variations in the soil and reduces the amount of cracking in the walls bearing on the foundation wall as well as in the foundation wall itself. If there are windows in the upper portion of the foundation walls, the upper band of reinforcement should be placed just below the windows. Poured-concrete foundation walls reinforced in this manner are entirely appropriate even for small structures such as residences. The additional cost is small and the results secured may be worth many times this cost. Two-way continuous footings may be constructed, as shown in Fig. 18*a*, to reduce differential settlement more effectively than can the one-way continuous footing. Foundations tied together in this manner are desirable from the point of view of earthquake resistance.

Raft or Mat Foundations. These usually consist of reinforced concrete slabs from 4 to 8 ft. in thickness, as shown in Fig. 18*b*, covering the entire foundation area. These slabs or mats are reinforced with layers of closely spaced reinforcing bars running at right angles to each other and about 6 in. below the top surface of the mat and other layers about 6 in. above the bottom. It is preferable to pour the entire slab in one operation in order to avoid construction joints. Another form of raft or mat consists of inverted T beams of reinforced concrete, as shown in Fig. 18*c*, with the slab covering the entire foundation area. The beams run in both directions and intersect under the columns. These are poured at the same time as the slab, forming a *monolithic* structure which will act as a unit. Before the basement floor is placed, the space between these beams may be filled with cinders or other materials as shown in the figure. If the slab is placed at the top of the beams and monolithic with the mat, as shown in Fig. 18*d*, the mat may serve as the basement floor and save excavation and filling. This

construction is suitable for a soil which will stand without caving so that the space occupied by the beams can be excavated and the whole mat poured without the use of forms. Raft or mat foundations are used

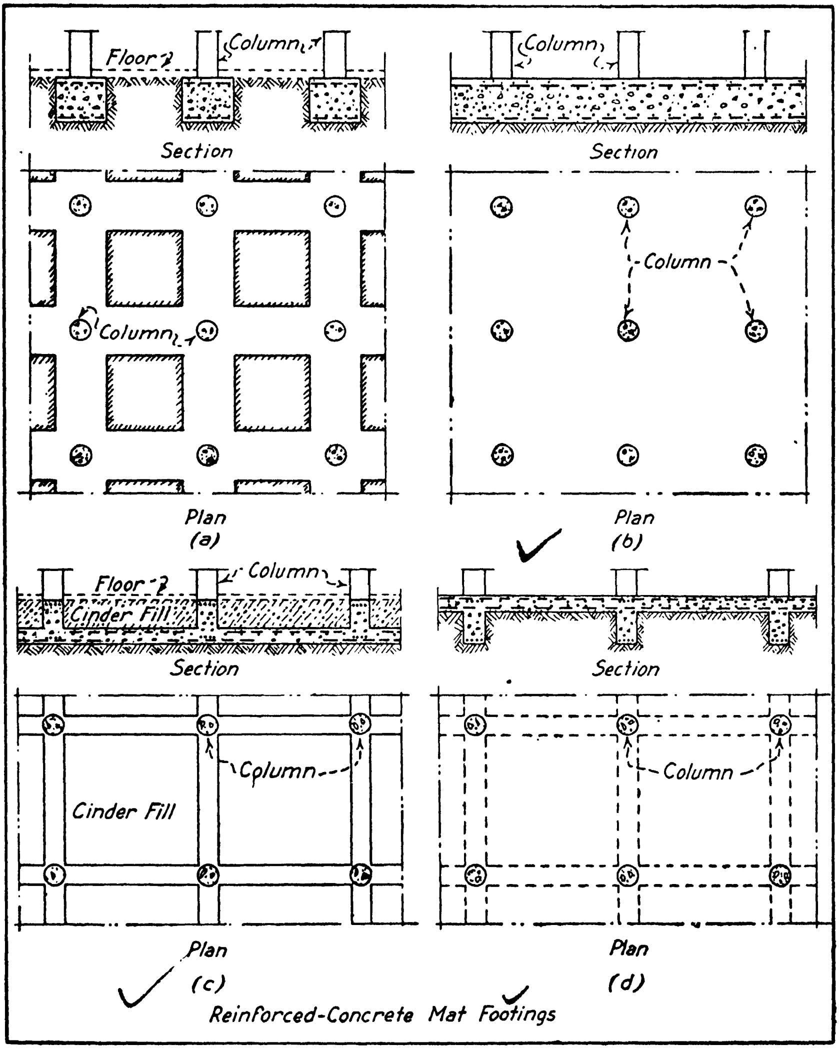


FIG. 18. Raft or Mat Foundations

when the bearing power of the soil is so low that spread footings can not be used and where piles can not be used advantageously or are not necessary. Foundations of this type are commonly called *floating foundations.*

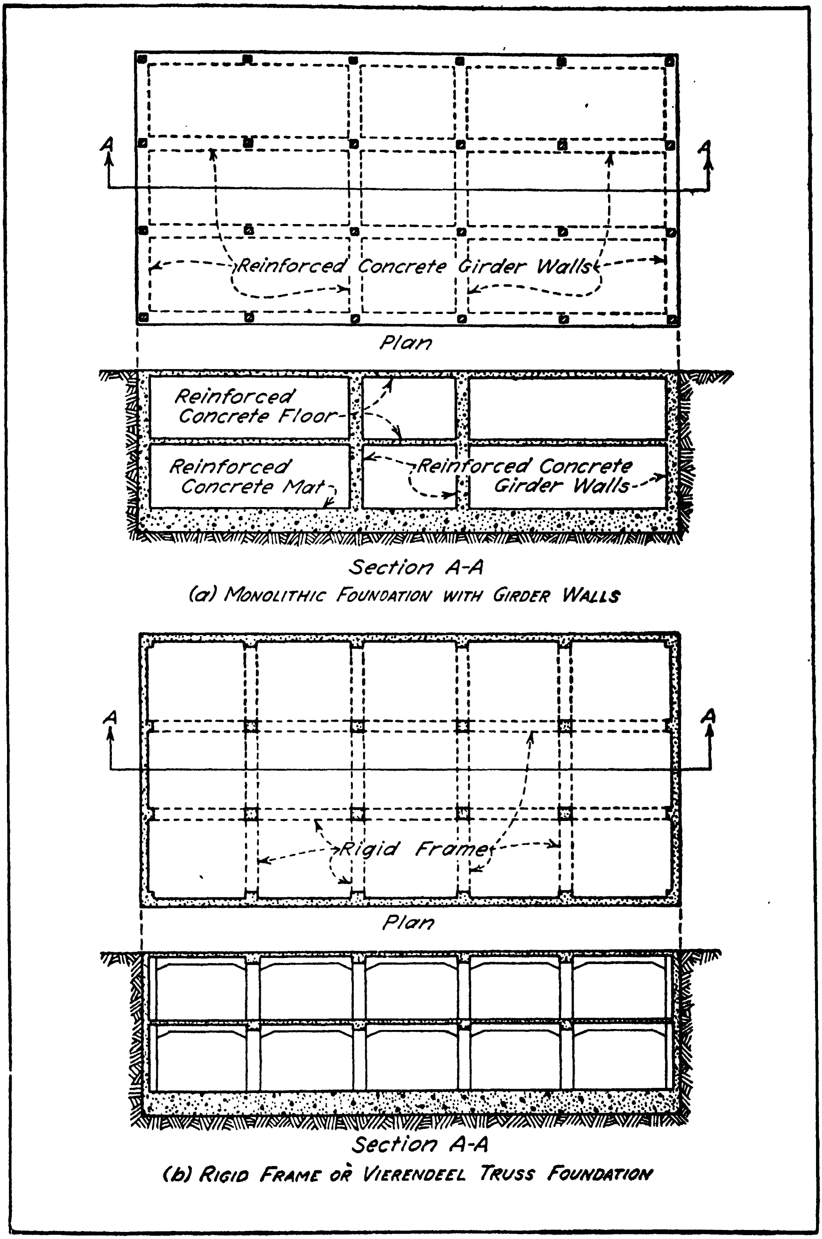


FIG. 19. Rigid Foundations

Rigid foundations. During recent years there has been a tendency to use the term floating foundations in a more restricted sense to apply to foundations where the earth is excavated to a depth that will make the weight of the earth removed about equal to the building load as with a body floating on a liquid.[6,7] In such a case, the total vertical pressure on the soil under the building is about the same after the building is completed as it was before the excavation was started and the settlement is reduced to a minimum. All settlement can not be eliminated because there is an elastic rebound in the soil when the earth load is removed and a corresponding deformation when the building load is added. If a foundation is not rigid and is well below the ground surface, the central portion of the building probably will settle more than the outer portion.

In order to reduce this differential or uneven settlement to a minimum, foundations must be so constructed that they are very rigid. There are two ways of accomplishing this. One is to make use of rigid, reinforced concrete outside and cross walls in the basement of the building, to form a boxlike structure,[8] as illustrated in Fig. 19*a*, and the other is to design the basement floor and the first or second floor as chords and the columns as posts of rigid frames,[9] as shown in Fig. 19*b*. Frames of this type are called *Vierendeel girders* or trusses. They are not really trusses, as defined in Art. 34, because they are not made up of triangular frames. Because the diagonal members are omitted, the members and their intersections must be designed to carry bending stresses. These rigid girders may also be carried through two or more stories if necessary to secure the required rigidity. This is conveniently done if there is a sub-basement, as often there is, or if one is provided to remove the weight of this soil in order to offset the building load. Reinforced concrete trusses with diagonals have been used instead of the Vierendeel girders mentioned above.[6] Reinforced concrete interior walls restrict the use of basement space. Openings in these walls reduce the rigidity of the walls and introduce problems in design. Reinforced concrete trusses with diagonals also restrict the use of the space. Vierendeel girders do not have this objectionable feature. More detailed information is given in references 7 to 11 at the end of the chapter.

ARTICLE 16. SOIL PRESSURES UNDER SPREAD FOUNDATIONS

General Discussion. The design of spread foundations and settlement computations are based on the distribution of pressures at the surfaces of contact between the foundation and the soil, often called the *foundation bed,* and in the underlying soil. These pressures have been

measured by various investigators and methods for computing them have been developed. The measured pressures are subject to the uncertainties which exist in most *pressure cells* that have yet been developed for measuring soil pressures, but reasonably satisfactory data are available to correlate experiment and theory. The computed pressures are determined by analytical methods which assume that soils have certain properties which they possess only to a fair degree. The most widely used method is that developed in 1885, by Boussinesq, for a homogeneous, isotropic, elastic solid with the load applied at the surface and normal to it. Various proposals have been made for modifying Boussinesq's solution so that it will more nearly apply to soils, but none has received general recognition.[12,13,14] The pressures which are of interest in foundation computations are the unit vertical pressures on horizontal surfaces at various depths below the surface. The calculation of these pressures, using Boussinesq's method directly, is quite laborious but a procedure developed by Newmark[15] has greatly simplified the computations. Boussinesq's solution applies to the pressures produced in the soil by superimposed loads. These pressures are of interest in settlement computations. In building foundations, the settlements or deformations which would accompany stresses approaching the ultimate strength of the soil are normally many times as great as could be permitted so that the ultimate strength of a soil is not usually of interest.[9] However, some instances where ultimate strength is of importance will be considered subsequently.

Contact Pressures. The actual distribution of the normal pressure on the surface of contact between the bottom of a footing and the soil is of interest. The analytical solution based on the idealized properties mentioned above, and with the footing assumed to be perfectly rigid, gives the stress distribution shown in Fig. 20*a* with infinite, unit, normal pressures at the edges. Actually no material could be perfectly elastic for infinite stresses so that the pressures under the edges will have some large finite value. The distributions for rigid plates on clay and sand have been determined experimentally, with the results shown in Fig. 20*b*.[16] The contact pressures for clay were found to have a distribution similar to that given by the analytical solution. As the depths of the footing below the surface increased, the proportionate difference between the edge pressures and the center pressure decreased. Also, it seems probable that the pressure distribution in clay will gradually change and become more uniform as the clay consolidates under pressure.[9] The contact pressures for sand were found to be a maximum at the center and zero at the edges, where the footing was on the surface.[17] This is as would be expected because the sand

grains under the edge of the footing have no lateral support and so can carry no vertical stress. With clay, cohesion provides this lateral support. When the footing is below the surface, edge pressures are developed because the sand grains under the edge now have lateral support which is proportional to the depth below the surface. However, this lateral support increases as the center of the footing is

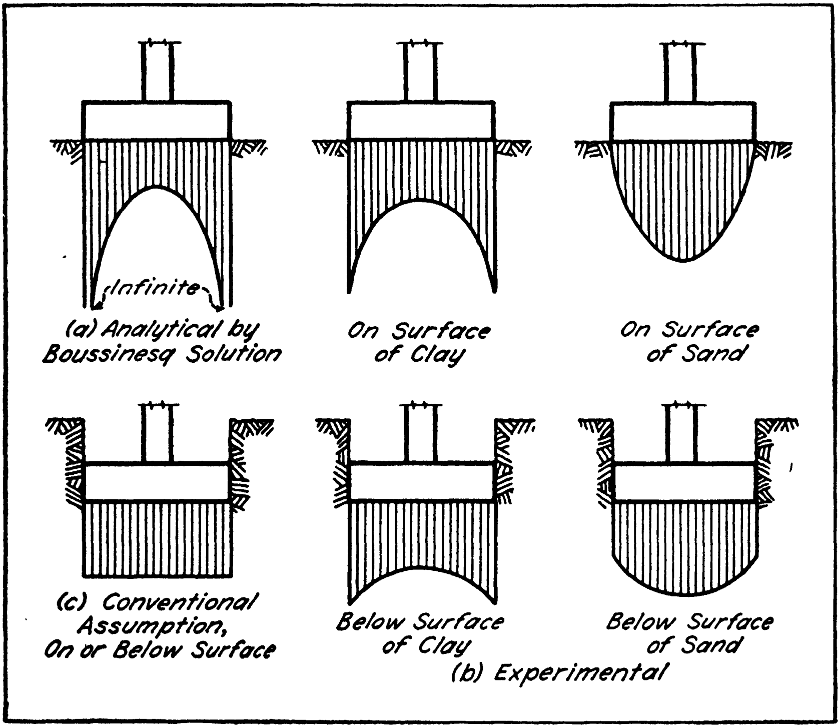


FIG. 20. Contact Pressures

approached and the pressures increase accordingly. The common practice in the design of footings is to assume a uniform pressure distribution as shown in Fig. 20*c*. The effect of other distributions should at least be considered, especially in combined and continuous footings and in raft foundations.[9] The effect of the elastic deflection of the foundation itself on the distribution of foundation pressures should be considered in some instances. According to Terzaghi:

For foundations on well compacted sand, the pressure-relieving effect of the deflections is very important indeed but, for soft soils, this is insignificant. . . . Since raft foundations are supported on soft soils, designers do not often

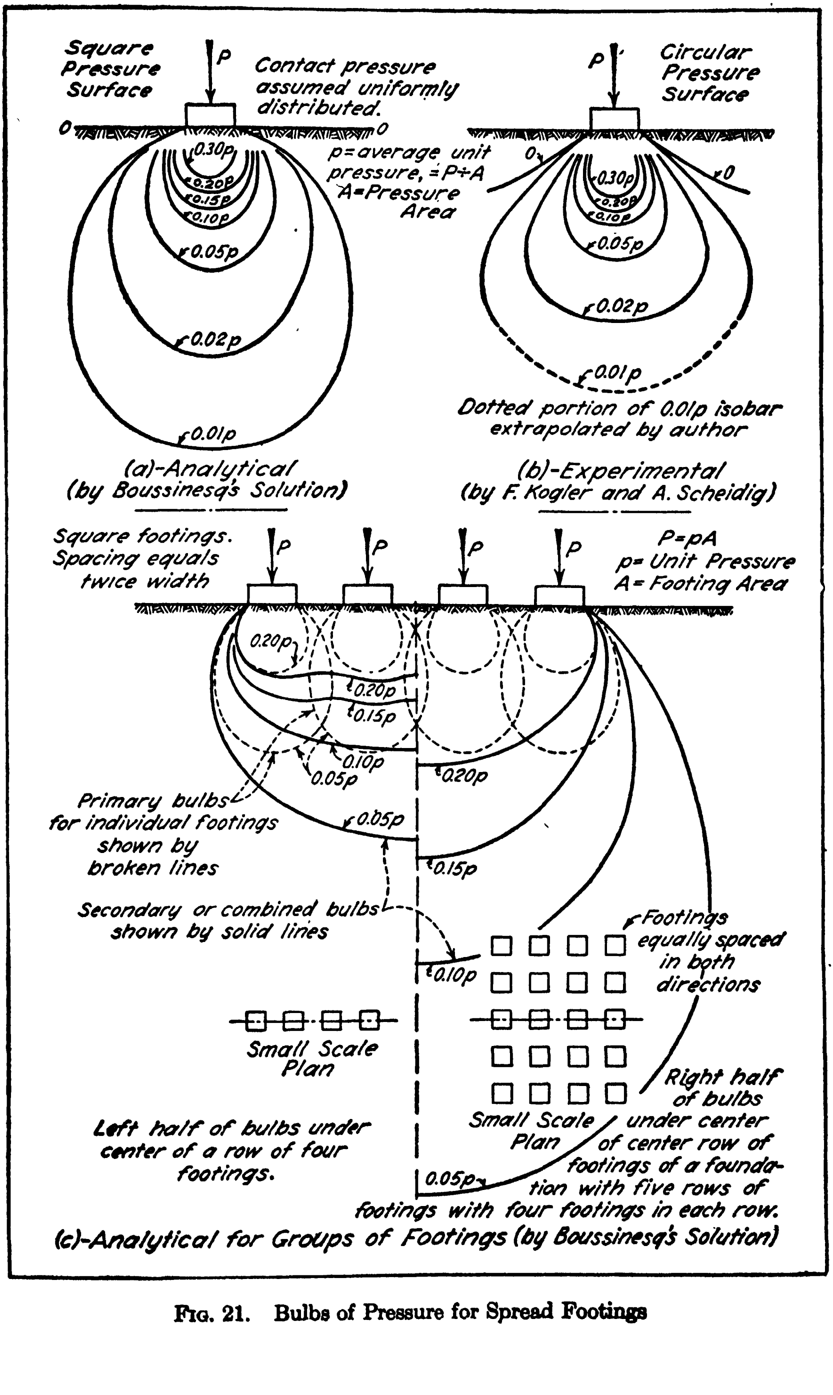


FIG. 21. Bulbs of Pressure for Spread Footings

have an opportunity to take advantage of the pressure-relieving effect of deflection.[20]

The effect of the distribution of contact pressures on the unit vertical pressures under a footing does not extend deep enough to be of any importance in settlement computations.

Pressure Bulbs. The *unit vertical pressures* under a square footing, as computed by Boussinesq's solution are shown in Fig. 21*a*, and experimental values, determined by Kogler and Scheidig,[18] for a cir-

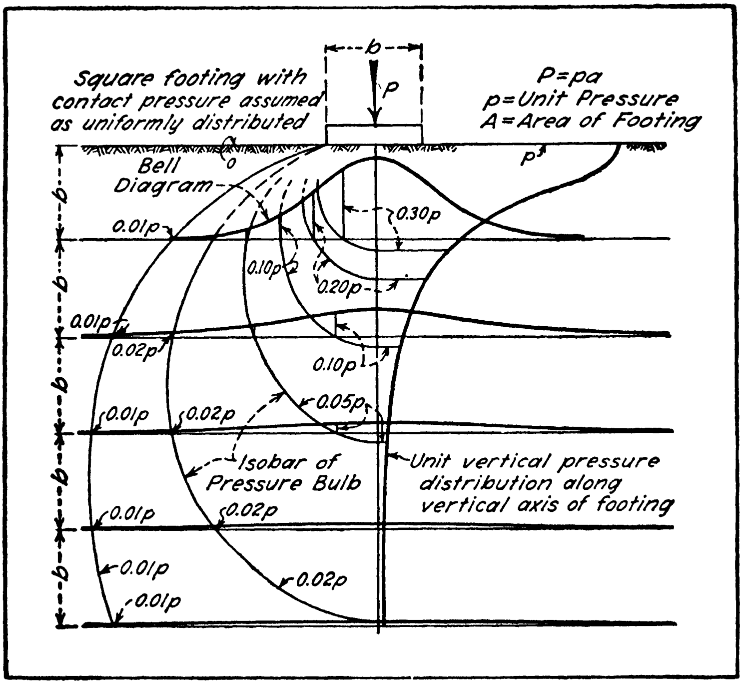


FIG. 22. Relation between Bell Diagrams and Bulb of Pressure

cular plate on sand are shown in Fig. 21*b*. In each of these figures the values given are of unit vertical pressures at points in a vertical plane parallel to the paper and through the center of the loaded surface. The magnitudes of the pressures at various points are indicated by lines, sometimes called *isobars*, drawn through points of equal vertical pressure. These figures are called *pressure bulbs* because of their form. The dimensions of computed pressure bulbs are directly proportional to the width of the loaded area. It is assumed that this proportionally applies to pressure bulbs in actual soils, but the variations

which occur in the soil do have some effect on the dimensions of the bulb. Instead of including several isobars in a single bulb, as shown in Figs. 21*a* and *b*, a separate bulb is sometimes drawn for each intensity of pressure.[19] As stated in the preceding paragraph, the distribution of the contact pressures is different for clay and sand, but the effect of this difference extends only a short distance below the surface. The upper portions of the pressure bulbs for clay and sand are therefore different, but otherwise they are considered identical.[70]

The isobar for zero stress is at the surface for Boussinesq's solution, as shown in Fig. 21*a*, but for the experimental bulb it extends downward and outward from the edge of the footing, as shown in Fig. 21*b*. It should be noted that this isobar does not close. It can not pass under the footing, as do all other isobars, because nothing would be supporting the load along the surface of which this line is a trace.

Buildings are usually supported on several footings. The pressure bulbs for the individual footings gradually merge into a single bulb for the entire foundation, as shown in Fig. 21*c*.

Bell Diagrams. The distribution of unit vertical pressures along horizontal planes at various depths under a footing is illustrated by the diagram in Fig. 22. These are called *bell diagrams* because they are bellshaped. The " stress volume " included under each of these diagrams is equal to the load. The pressure bulb corresponding to the bell diagrams is shown in the figure. The ordinate of the bell diagram at each point where an isobar crosses the corresponding horizontal line is equal in magnitude to the pressure represented by the isobar. The distribution of unit vertical pressures along a vertical line through the center of a footing is shown in Fig. 22. The abscissas in this figure are equal to the corresponding midordinates of the bell diagram. A pressure bulb corresponds to a contour map, and a bell diagram to a profile.

ARTICLE 17. BEARING POWER OF SPREAD FOUNDATIONS

General Comments. Present methods for determining the bearing capacity of soils are unsatisfactory. The most common procedure consists of selecting values from tables of allowable or presumptive bearing capacities given in the local building codes. Such tables are commonly copied from other codes and there may be little justification for the values given. Some tables, however, are based on extensive investigations and experience and are usually satisfactory for ordinary buildings.[70] In these tables, soils are usually divided into classes by indefinite terms, such as soft, medium, and hard clay, and a bearing value is given for each class. Actually, the bearing pressure which should be selected depends upon the amount of settlement which is

permissible.[20] The pressures under the foundations of buildings are rarely large enough to approach the actual strength of the soil[9] except shallow foundations on soft clay.

For foundations supported on cohesive soils, such as clay, the settlements of footings for a given unit pressure increase with the linear dimensions of the footings,[20] at least for the smaller sizes. The common assumption that the settlements of footings that rest on a given soil will be equal if the unit pressures are equal is incorrect for cohesive soils. There would, therefore, be a different allowable pressure for each size of footing on a given cohesive soil if uniform settlement is required. However, some unequal or *differential settlement* between footings may not be serious. The difference in the amount of settlement which may be permitted for the various footings, and which will not overstress the structural frame, should be decided upon. Foundation science has not developed to a point where such a procedure can be carried out, except possibly on important structures where experts can be employed and extensive tests can be made. In the absence of more elaborate investigations, experience with other buildings on similar soil may yield valuable information, and loading tests of the soil, such as described later in this article, are sometimes of value if properly made and interpreted.

The selection of allowable bearing values by examining only the soil at or near the surface on which the foundation is to rest may lead to serious errors. The soil below the bottom of a footing, for a depth of 1½ to 2 times the width of a footing, contributes significantly to its settlement and the underlying soil may be very different from that near the surface.[19] Layers of peat, soft clay, and other soils of low bearing power at even greater depths may contribute considerably to settlement. Another factor which is commonly neglected in selecting allowable bearing values is the usual increase in bearing capacity with increases in the depth of the bearing surface below ground surface.[46] This is due to increased stability resulting from the weight of the soil surrounding the footing and above the level of its bearing surface.

Table of Allowable Bearing Capacities. The following table of allowable or presumptive bearing capacities, taken from the 1938 edition of the "Building Code" of New York City, will serve as an example.

That the bearing capacity of an underlying stratum in some instances is less than that of the soil on which a foundation rests is recognized by a code proposed for the City of Boston[46] in the requirement that the unit pressure due to the footing load computed on the top surface A–A of the weaker stratum, as shown in Fig. 23, shall not exceed the allow-

MAXIMUM ALLOWABLE OR PRESUMPTIVE BEARING CAPACITIES

(According to the Building Code of the National Board of Fire Underwriters, 1934, and the Building Code of New York City, 1938)

Type of Soil	Tons per Sq. Ft.
Hard sound rock	40
Medium-hard rock	25
Hardpan overlying rock	10
Soft rock	8
Gravel	6
Coarse sand	3
Hard dry clay	3
Sand and clay, mixed or in layers	2
Firm clay	2
Fine and wet sand (confined)	2
Soft clay	1

able bearing pressure for the material in that stratum. The load here is considered uniformly distributed over the area intercepted on the top surface of the weaker stratum by planes sloping from the edges of the foundation at an angle of 60 deg. with the horizontal, as shown in the

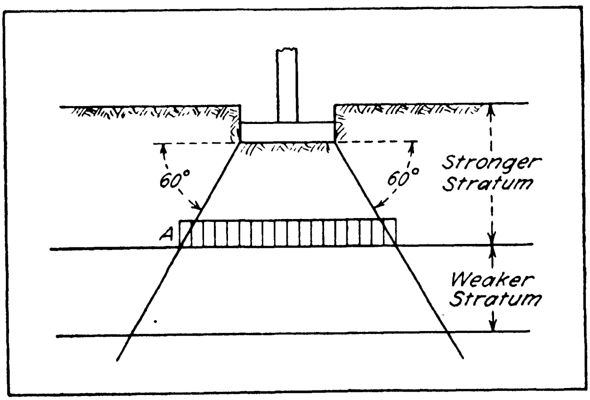


FIG. 23. Assumed Distribution of Vertical Pressures under a Footing

figure. It is recognized that this is an arbitrary assumption and does not follow the form of the bell diagram shown in Fig. 22. However, the procedure is considered sufficiently accurate for its intended purpose and is simple in its application.

Allowable bearing pressures on underlying soil are considered as pressures which the building can add to the pressures which are already there. This is equivalent to neglecting the weight of the soil in determining the pressures on underlying soil, for comparison with allowable values.

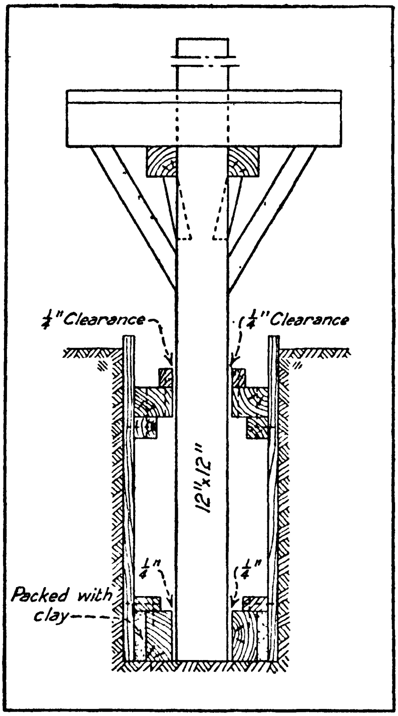


FIG. 24. Apparatus for Tests on Bearing Power of Soils

Bearing-Capacity Tests. As has been stated, the allowable bearing pressures to be used are often based on tests which consist of placing a load on the soil and observing the settlements which occur as the load is increased. One type of loading apparatus used is shown in Fig. 24. The surface in contact with the ground is usually 1 ft. square, but occasionally an area 2 ft. square is used. If the supporting soil is clay, two or more different areas are sometimes used in an effort to establish the relation between size of area and the amount of settlement for a given unit pressure. The load is obtained by piling pig iron, sand bags, cement, brick, or other available material on the platform. Level readings are taken to determine the magnitude of the settlements. No uniform procedure exists for determining the relation between the bearing power, the applied load, and the amount of settlement. The provisions of the 1938 "Building Code" of New York City are in part as follows:

Each test shall be made so as to load the soil over an area of at least 4 sq. ft. and so that the load is applied continuously throughout the test.

The loading shall proceed as follows: *a*. The load per square foot which it is proposed to impose upon the soil shall be first applied and allowed to remain undisturbed, and readings shall be taken at least once every twenty-four hours in order to determine the rate of settlement. The applied load shall remain until there has been no settlement for a period of twenty-four hours.

b. After the requirements of clause *a* are met, an additional 50 per cent excess load shall be applied and the total load allowed to remain undisturbed until no settlement occurs during a period of twenty-four hours, careful measurements and readings being taken at least once every twenty-four hours in order to determine the rate of settlement.

The test shall be considered unsatisfactory and the result unacceptable if the proposed safe load shows more than $\frac{3}{4}$ in. settlement, or the increment of settlement obtained under the 50 per cent overload exceeds 60 per cent of the settlement obtained under the proposed load.

Procedures for interpreting loading-test data, such as that which has been given, are arbitrary and not entirely satisfactory, but the present knowledge of soil behavior is inadequate to formulate better procedures which are feasible for use in building codes. Test loads are usually applied in pits whose bottoms are at the elevation of the bottoms of the proposed footings. The results are affected by the relation

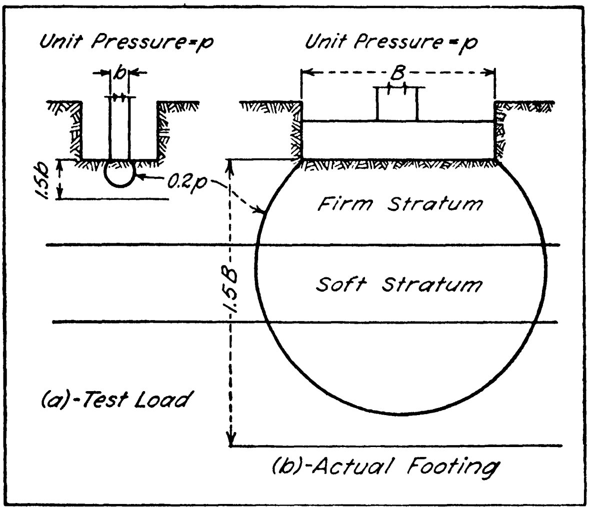


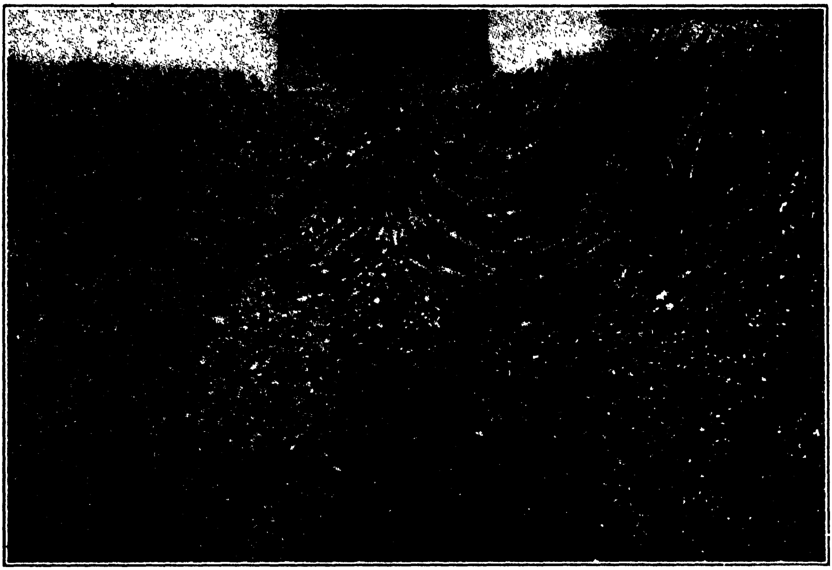
FIG. 25. Comparison of Pressure Bulbs for Test Load and for Actual Footing

between the test area and the area of the bottom of the pit. If the test area occupies a large portion of the area of the pit bottom, the loaded soil receives considerable support from the soil surrounding the pit, but if only a small portion of the bottom is loaded, this support may be unimportant. Experienced judgment, guided by examination, and tests of the underlying soil, must be used in the interpretation of such test results.

This type of test may be of no value in determining the bearing capacity of a soil for the reasons which follow. The significant pressure bulbs, so far as settlement is concerned, for the small area of a test load and for the larger area of a footing with the same intensity of load are shown in Fig. 25. It is seen that the soft underlying layer has little effect on the settlement of the test load. However, it may account for most of the settlement of the actual footing. For this reason, a test load may not be a true index of the settlement which can be expected in an actual footing.[19] It should always be accompanied by test

borings which reveal the nature of the underlying soil. Also, the effects of time and of the size of bearing surface must be considered.

Ultimate Bearing Capacity. As has been stated, the bearing capacity of a building foundation is usually determined by the permissible settlement, but sometimes actual rupture of the soil may occur.



M. L. Enger

FIG. 26. Displacement of Sand Due to Surface Load[21]

When a load is placed on soil, shearing stresses are set up in the soil which tend to cause the grains to move in relation to each other. This is demonstrated by the photograph in Fig. 26, which is a time exposure taken as a rod was forced into sand contained in a box with the exposed side made of plate glass. A flat side of the rod was placed next to the glass. The path of movement of each grain of sand in contact with the glass, during the period when the camera shutter was open, is recorded on the photograph.[21] A similar phenomenon has been observed in clay.[22] The vertical movement of the rod in Fig. 26 is much greater relatively than would be expected in a footing, but the photograph illustrates the tendency for the soil under a footing to be displaced laterally and upward. As has been stated, such displacement is not usually a significant factor in foundation settlements of buildings, but it may occur under excessive or unsymmetrical loads. From Fig. 26, it is seen that the soil grains in the region near the rod move outward and upward along curved paths and that heaving occurs at the sur-

face on each side of the rod. It is also seen that, outside a fairly definite boundary, the soil is not displaced. In the disturbed region, the shearing stresses along the curved paths, caused by the load, exceed the shearing resistance of the soil, but, in the undisturbed region, the shearing resistance exceeds the shearing stresses. The displacements which occur are illustrated by the diagram in Fig. 27. Analytical solutions have been devised for computing the maximum load which a soil, whose shearing strength is known, will carry. Probably the best known of these is that proposed by Krey.[23,70]

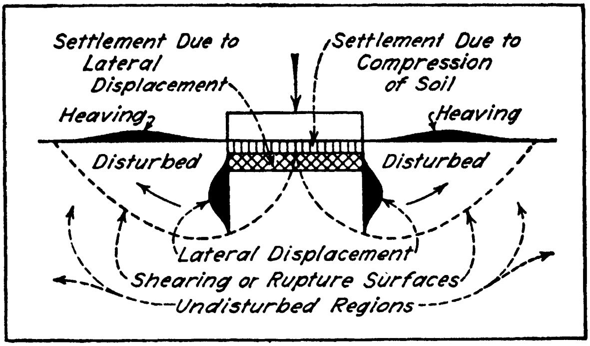


FIG. 27. Causes of Settlement of Footing

Failure of Earth Slopes. Earth slopes may fail by rupture with no load except that of the weight of the earth itself as evidenced by landslides. Buildings placed on or close to a sloping earth surface may contribute to such failures and may be damaged or destroyed by them. In some buildings, the failure is very slow and is foretold by excessive cracking in the building if only a part of the building is affected or by gradual settlement. In other buildings, the failure may be sudden, due to weakening of the soil by rain and due to increasing the weight of the soil by the rain water absorbed and by the force exerted by water seeping through the soil. In some buildings the effect of earthquake shocks should be considered.

The usual manner of failure of earth slopes is shown in Fig. 28. A portion of the earth embankment designated as *ABC* tends to slide on the curved surface, *BC*, and pile up in the position shown by irregular lines. If a part or all of a building occupies the portion of the horizontal surface affected the building will be damaged or will collapse entirely. Experience has shown that earth slopes, except clean sand or gravel, fail on surfaces which are roughly curved. In computations of the stability of earth slopes, it is usually assumed that failure

will occur on a smooth curve which may be considered an arc of a circle. The portion of the slope which tends to slide is considered as tending to rotate about O, the center of the circular arc. The resistance to failure is offered by the shearing strength of the earth along the arc. If the moment $W \cdot a$ in Fig. 28a of the forces tending to cause failure is greater than $T \cdot r$, the moment of the resisting forces, failure will result. If $W \cdot a$ is less than $T \cdot r$, the slope is stable, the factor of safety being measured by $T \cdot r \div W \cdot a$. The arc BC, on which failure is most likely to occur, must be located by trial since it is the arc which will give the least factor of safety in the computations. If a building is

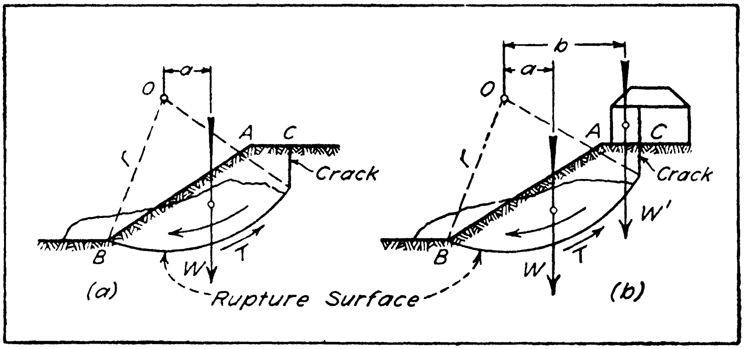


FIG. 28. Failure of Earth Slopes

located on top of the slope, as shown in Fig. 28b, the weight W' with the moment arm b must be included in the computations. Where forces other than these exist, they are, of course, taken into account. It can be seen that a slope which is stable, before a building is built, may fail because of the load added by the building. Buildings should not be located on or close to clay slopes unless serious consideration is given to the danger of failure from the causes which have been outlined in this paragraph. Other structures besides buildings, such as retaining walls, may also fail in this manner. Analytical methods for investigating the stability of earth slopes are available.[24]

Bearing Capacity of Rock. Rock gradually grades into soil and so no definite value can be given for the bearing capacity of rock. Allowable values for the bearing power of rock, as given in building codes, range from 10 to 100 tons per square foot. The lower value is for weathered, shattered, and poorly cemented rock; and the higher value, for sound, thoroughly cemented rock. It is often said that sound bed rock will carry any load which can be transmitted to it by a concrete pier, considering that the allowable unit compressive stress in the con-

crete of the pier would be less than the allowable bearing stress in the rock. A given material is stronger in bearing, where the load is applied to a small portion of its surface, than it is in a prism such as a pier. The only way that failure in bearing could occur is by shear in a manner similar to the failure of soil that carries a surface load, as illustrated in Fig. 27. As stated in Art. 12, some shales yield by plastic flow when subjected to bearing pressures. For this reason, shales should always be carefully investigated before they are subjected to large bearing pressures.

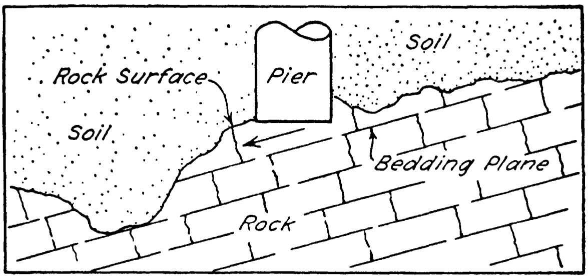


Fig. 29. Tendency To Slide along Bedding Plane

When rock which is being considered for foundation support is of doubtful quality, compression tests should be made as an aid in judging and deciding upon a safe bearing value. The bearing pressures allowed by the 1938 " Building Code " of New York City are given earlier in this article, but they are in general terms.

Other factors which must be taken into account in examining rock for proposed foundations are the direction of stratification as illustrated in Fig. 29, structural defects, such as excessive fractures; caverns and solution channels in limestone, possibly weak underlying strata. If a fault crosses the building site, the possibility of movement along the fault, and the consequences of such movement, should be considered.

As has been stated, a test hole yielding a core should be drilled to a depth of 10 ft. or so in the bottom of a rock excavation on which a pier is to be placed. The hole and the core will reveal any objectionable structural defects or unsatisfactory underlying material which may be present.

ARTICLE 18. SETTLEMENT OF SPREAD FOUNDATIONS

General Discussion. All foundations, except those supported on sound rock, settle. When the supporting soil is dense, coarse sand or gravel, the amount of settlement is small, unless the loads are excessive,

and occurs as soon as the load is applied. In contrast to sand and gravel, if the supporting soil is clay, the settlement may be large and will continue over a period of many years. In extreme cases, the settlement of structures founded on clay is measured in feet.

Settlement may not be objectionable if the entire foundation of a building settles, uniformly, if the amount of settlement is not excessive and if it can be predicted within reasonably close limits, before construction starts. Such settlement causes no structural damage to the building. However, *differential settlement*, or different amounts of settlement in different parts of a foundation introduces stresses which may seriously weaken a building, throw various parts of the building out of plumb, cause unsightly cracks in walls, partitions, floors and ceilings, cause floors to be out of level and uneven, cause roofs to leak, interfere with the operation of doors, and throw mechanical equipment out of adjustment.

It is commonly assumed in the design of spread foundations that, if the supporting soil is fairly uniform over the building site, settlement will be uniform if the unit pressures exerted by the foundations where they come in contact with the soil are the same for all parts of the foundation. In computing these pressures, only the weight of the building and that portion of the contents which remains in place for long periods are considered the cause of settlement. Also, the maximum unit pressure in any part of the foundation for any possible condition of loading is commonly limited to some rather arbitrarily adopted value. That this practice is unsatisfactory, particularly for cohesive soils such as clays, has become increasingly evident during recent years because of experience with actual foundations and because of experimental and theoretical investigations which show that, within certain limits at least, the settlement for a given unit pressure on a given cohesive soil increases as the lineal dimension of that area increases.[20] This practice has also been unsatisfactory because of the inadequate and faulty methods used for determining the allowable bearing capacities of soils. If foundations are supported on cohesionless soil such as sand, the amount of settlement for a given unit pressure is independent of the size of the footing, so that the assumptions referred to above are more satisfactory than for foundations supported on clay.

Causes of Settlement. The possible causes of settlement of foundations supported by soil are as follows:

1. Compression of the soil grains themselves.
2. Lateral displacement of the supporting soil.
3. Reduction in the volume of the voids of the supporting soil and, therefore, in the volume of this soil.
4. Actual rupture of the soil.

The first of these possible causes is negligible because the unit stresses in the soil grains, for the loads which are placed on foundations, are too small to be of any consequence.

For the loads usually placed on building foundations, the lateral displacement of the soil is so small that it need not be considered[9] unless the lateral support of the soil is reduced by adjoining excavations or unless shallow foundations bear on soft clay.

The principal and usually the only important cause of settlement of building foundations is the third, i.e., the reduction in the volume of the voids in the supporting soil. These voids may contain air or other gas or water. When a load is applied to the soil there is a tendency to decrease the volume of the voids. Air and other gases are readily compressible and are difficult to confine. Thus they offer little or no resistance to forces which tend to reduce the volume of the voids. Water may be considered incompressible for the unit pressures encountered in foundations; and so, if the voids are filled with water, a part of this water must be forced out of the voids, or be removed by drying out, before settlement can occur. Since sand is highly permeable, water is readily forced out of the voids and settlement takes place very rapidly. Also, the percentage of voids in sand is small and the amount of settlement is correspondingly small. If the sand is not in a dense condition, settlement may be caused, without any increase in load, by vibrations from machinery in a building, from pile driving for adjoining buildings, from passing traffic, or from other causes. This is due to a decrease in volume resulting from a rearrangement of the sand grains.

All clays are relatively impermeable, but there is a great difference in clays in this respect. The voids of natural deposits of clay are usually filled with water.[20] When such deposits are loaded sufficiently, the pressure in this water rises and most of the load is carried by the water. Because the pressure in the water in the voids of the soil under the load is higher than that in the water of the surrounding soil, a part of the water is gradually squeezed out of the voids in the soil under the load, the volume of the voids is decreased, and settlement occurs. The amount of settlement is relatively large because the percentage of voids in all clays is large. However, it is much greater in some clays than in others, as may be seen by consulting Art. 12. As has been stated, the rate at which a foundation supported by clay settles depends upon the permeability of the clay. It also depends upon the distance water will have to travel to reach a porous stratum or the ground surface where water can escape. Usually the settlement of buildings founded on clay continues for years. The process of reducing the volume of soil by squeezing out the water is called *consolidation* and was explained briefly in Art. 12.

In order for the settlement due to consolidation to take place as explained in the last paragraph, it is necessary that the foundation pressures in the clay be sufficiently high to break the bond between the clay particles, illustrated in Fig. 12; for if this bond is maintained the reduction in the volume of the voids and the corresponding settlement are relatively small.[66,67]

From this discussion, it is evident that any operation which will improve the drainage of clayey soil supporting a building tends to increase its settlement. The construction of sewers, drains, wells, subways, and other buildings in adjoining areas may have this effect. Also, long periods of drought may reduce the moisture content of the soil supporting a building and cause settlement even though no settlement has occurred for many years. Saturated sand under a foundation tends to flow if lateral support is removed even though the operation is at a considerable distance from the foundation.

As explained in Art. 15, the most effective method for reducing the settlement of foundations supported on a deep bed of soft clay is to excavate the basement of the building to a depth sufficient to make the weight of the soil removed equal to the weight of the building. In this way, any increase in the soil pressure due to the building load is avoided and the only settlement which will occur is that due to the rebound of the soil in the bottom of the excavation, the altered distribution of the pressures, and the hydrostatic changes outlined above.

Effect of Adjoining Buildings. Unless buildings are widely separated, each building affects adjoining buildings adversely in many respects. Adjoining buildings interfere with each other's natural light and ventilation and may increase the fire hazard. These factors are obvious and are well recognized.

In the business districts of cities, buildings commonly occupy the full width of their sites. Excavations extending to the property line remove the lateral support of the soil of the adjoining property and may injure that property through caving of the soil if support is not provided. The problem becomes more complicated if there is a building on the adjoining site. The legal responsibility under such conditions is discussed in Art. 13.

Other less obvious effects exist, such as the settlement of the adjoining building, because the improved drainage resulting from adjoining excavations facilitates the consolidation of the soil under the building, as mentioned in a preceding paragraph.

Foundations of existing buildings supported on water-bearing sand or silt may be undermined by adjoining excavations, because of pumping operations to control the water, and soft clay soils may squeeze into

excavations for piers. This condition is evidenced by the excess of the excavated material over the volume of the excavation. This excess of excavation, or *lost ground*, may result in a corresponding settlement of adjoining foundations.

Even though a building is constructed only to the limits of its own site, it causes vertical as well as lateral pressures in the soil of the adjoining sites. Because of the increase in the vertical soil pressures under the foundations of an existing building by the construction of a new building on an adjoining site, the existing building may settle.

A building may be damaged from the upheaval of the soil resulting from the reduction of soil pressures due to the removal of an adjoining building. Soils which will produce this effect are rare. This difficulty has been experienced in Mexico City.[63]

Settlement Predictions. According to Terzaghi:[26]

At present there is no method of predicting the settlement of buildings on sand or gravel foundations and the prospects for discovering such a method are very slight. . . . Current procedures for predicting the settlement of buildings on clay foundations are more promising; and, yet, according to reports, the application of these methods requires elaborate investigation and is limited to important structures. In every other case the engineers must estimate the settlement on the basis of previous experience. Such experience can be acquired only by systematic settlement observations.

Settlement predictions for structures founded on clay are based on the consolidation phenomenon. They are made by computing the unit vertical pressures, due to the building load, at various depths below the bottom of the foundation and by making consolidation tests on representative samples, at various depths, of the soil which is to support the building. The procedures followed in computing the unit vertical pressures are considered in Art. 16. The consolidation test is made in a specially designed apparatus in which the soil sample is compressed and the time rate at which the sample deforms under a given unit pressure is observed, provision being made for water to escape at the top and bottom surfaces of the sample. Mathematical relationships have been developed which enable the settlements to be computed from the unit foundation pressures and the consolidation characteristics of the samples, due consideration being given to the location of porous strata. These samples should be in the same condition in the test apparatus as in the ground, or should be *undisturbed samples.* Fairly satisfactory devices for securing such samples have been developed, but much remains to be done. Settlement predictions require specialized knowledge and experience in that field and are not usually made by structural engineers and architects.

Since the pressure bulbs under a foundation, as illustrated in Fig. 16, spread downward and outward indefinitely as the pressures grow smaller, it is desirable to consider the depth of soil which must be included to secure significant results. According to Terzaghi, for a perfectly elastic, isotropic solid, such as considered in Boussinesq's solution, approximately 80 per cent of the settlement is due to distortion and compression within the pressure bulb, formed by the surface on which the unit vertical pressure is 20 per cent of the intensity of pressure on the loaded area. This bulb lies entirely above a depth, below the bottom of the loaded area, equal to about 1½ times the width of the area.[19] This same relationship may be taken as applying to soils, unless there is an unusually soft layer of clay or a layer of peat below this depth.

Upward Movement. The foundations of buildings may be forced upward by the expansion of some clay soils when the moisture content is increased by rains or even when concrete is poured in contact with the ground. Shrinkage occurs as the soil dries out. These movements may be pronounced enough to break up floor slabs and to crack foundation walls seriously. Such action has been reported in Texas[65] and Colorado, in this country, and in Burma, India.[64] Similar difficulties have probably been experienced in other localities. In some instances the soil which has caused the difficulty has been high in calcium carbonate. Holes dug by rodents have accompanied such difficulties and may have contributed to the result by facilitating the entrance of water into the soil. The only safe solution when this condition exists seems to be to carry the foundations, by piers or walls, deep enough to reach soil whose moisture content is stable or deep enough to penetrate through the troublesome soil.[64] Another suggestion which has been made is to use bearing pressures which are high enough to counteract the tendency to swell,[64] but this procedure has not always been successful.[65] In any event, where such soils exist, every effort should be made to keep rain water out of the soil by concrete aprons next to the building, at least under all downspouts; a drainage system may help, and concrete should not be poured directly against the ground. Foundation walls should be reinforced as suggested in Art. 15.

An upward movement of 4 ft. is reported in Mexico City, at a site where old buildings were removed and earth excavated for the National Lottery Building.[63] This was caused by the decrease in the pressures in the underlying soil, and not by swelling due to increased moisture content.

ARTICLE 19. TYPES OF PILES AND PILE FOUNDATIONS

Types of Pile Foundations. Pile foundations are similar to spread foundations in some respects. In spread foundations, the loads are transmitted directly to the soil, or possibly hardpan, by the foundation, but in pile foundations, the loads are transmitted first to the piles which, in turn, transmit them to the soil, hardpan, or rock. The upper end of a pile is called the *head* or *butt*, and the lower end the *point* or *tip*. The types of pile foundations are much the same as for spread footings, as far as the part bearing on the piles is concerned. An isolated or independent pile footing is illustrated in Fig. 30*a*. The member into which the upper ends of groups of piles are embedded is called the *pile cap*. A cantilever pile footing is illustrated in Fig. 30*c*, and a raft or mat in Fig. 30*d*. Combined and continuous pile footings corresponding to these types of spread footings are used extensively. Several types of piles are used, the most common being wood piles, precast concrete piles, cast-in-place concrete piles, structural steel piles, and steel pipe piles. Each of these types is discussed briefly in the following paragraphs.

Wood or Timber Piles. In this country, wood piles are usually tree trunks with the branches and, most of the time, with the bark trimmed off. They are driven with the small end down, except under special conditions. This end may be cut off square; it may be pointed; or it may be provided with a metal point called a *shoe*. When driving is not hard, unpointed piles are used, especially if the points rest on a hard stratum, as in the end-bearing or point-bearing piles. Driving through firm clay may be made easier by cutting blunt points on the piles. If the material penetrated contains boulders or other obstructions, metal points may be desirable.

Wood piles which are permanently below the ground-water level will last indefinitely, but consideration should be given to the possibility of the lowering of this level, as mentioned in Art. 13. Except in temporary construction, piles which are not entirely below the permanent ground-water level should be treated to prolong their life. Wood piles above the ground-water level may be weakened or destroyed by decay due to fungi, insects, and by marine borers, as described in Art. 8. They may be made more resistant to these agencies by preservative treatments. The preservative usually used on piles is creosote.

Almost any kind of sound timber that will stand driving, and that has adequate strength for the loads to be carried can be used for piles which are to be below the "permanent" ground-water level. The most commonly used woods, however, are the cedars and cypress, which are very decay resistant; Douglas fir, from which very long piles of

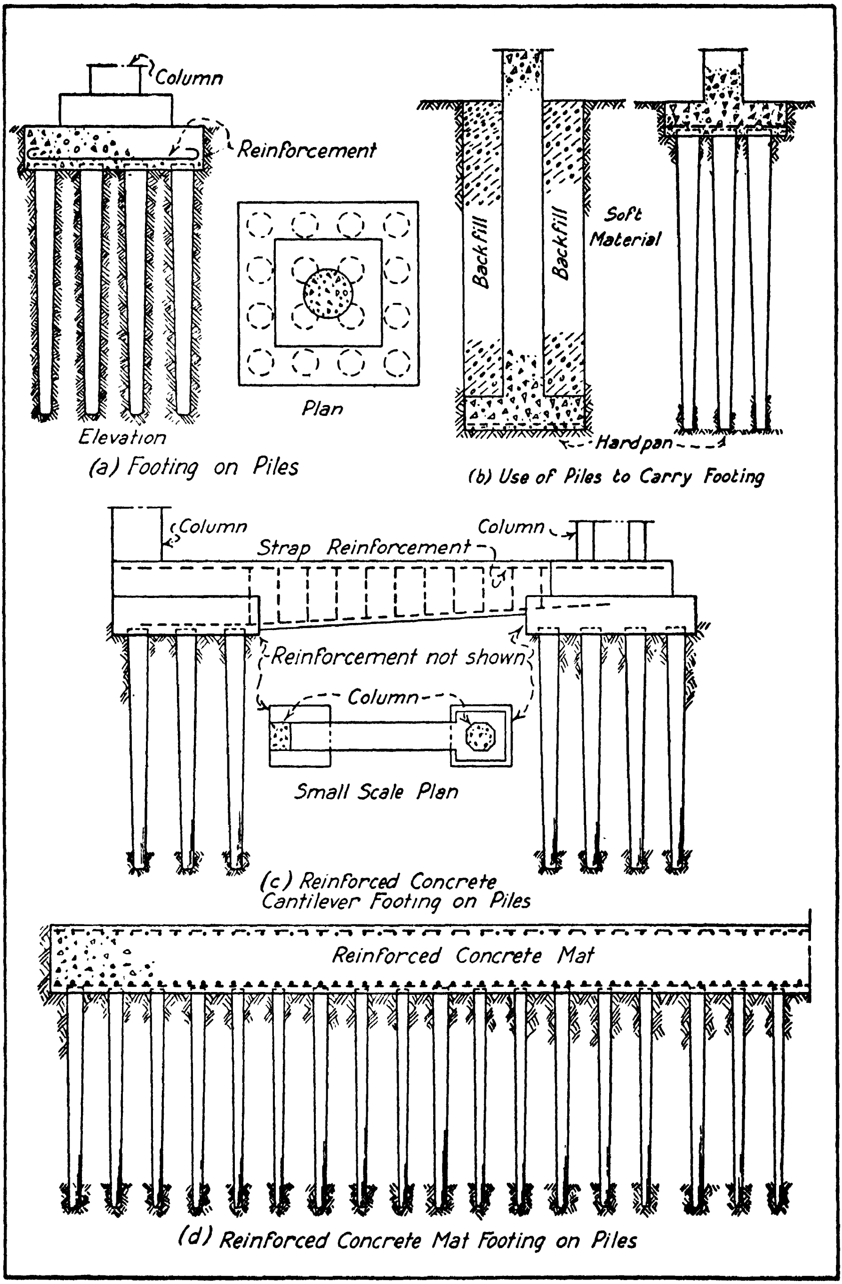


FIG. 30. Pile Foundations

excellent quality can be obtained; southern pine; white and red oak; and spruce. Douglas fir, southern pine, and red oak respond better to treatment processes than the other woods. In general, heartwood is more resistant to decay than sapwood, but better results are secured with sapwood than with heartwood in the treatment processes.[27]

The required dimensions for wood piles are determined by the load to be carried and the nature of the use. The diameter is rarely less than 6 in. at the tip and 12 in. at the butt and the taper should be uniform. Wood piles should be free from short or reversed bends, and a straight line extending from the center of the butt to the center of the tip should line wholly within the pile. Limbs and knots should be trimmed flush with the surface of the pile. In the better classes of work, piles should be peeled smooth.[27]

The above discussion concerns only piles formed from natural tree trunks because that type is almost exclusively used in this country; but in some parts of the world, where timber is not so plentiful, square-sawed timbers are used.[28]

Precast Concrete Piles. Piles constructed of reinforced concrete are used extensively. Sizes have varied from as small as 6 in. to as large as 24 in., and lengths have exceeded 100 ft. Piles are usually square or octagonal in cross-section; but they may be round, are usually of uniform section, except at the point, or may taper. The piles must be designed for the stresses caused by handling and driving, as well as for those produced by the loads to which they are subjected in service. In general, the bearing power of a pile is determined by the resistance offered by the soil to the load which tends to move the pile through the soil, rather than by the strength of the pile itself.[29] The reinforcement consists of longitudinal bars with hoops or spirals, as shown in Fig. 31*a*. If the reinforcing is provided only because of the stresses due to handling and driving, the thickness of the concrete outside the reinforcing need not exceed 1 in.; but, if the reinforcing is required by the service loads, it should be protected by at least 1½ in. of concrete; and, if exposure conditions are extreme, the protection should be 3 in. The top and point of the pile should be provided with additional lateral reinforcement to withstand the driving stresses. For piles driven in plastic clay soils, the point preferably should be blunt or even flat; while, for those driven in sand or gravel or which must penetrate hard strata, a long tapering point should be used. Where conditions are extremely severe, a metal point or shoe may be desirable. If piles are to be jetted into position, a pipe may be cast into the pile along its axis, the end of the pipe being contracted to form a nozzle.[30]

Cast-in-Place Concrete Piles. Concrete piles which are cast in place, or *in situ*, in the ground are of two general types, i.e., the shell or cased piles and the shell-less or uncased piles.

A *shell pile* is formed by driving a sheet-steel shell or casing, closed at the point, into the ground and filling it with concrete. In the *Raymond pile*, shown in Fig. 31*b*, the tapered shell is made of relatively thin sheet steel. This pile is formed by: (1) placing a steel mandrel or

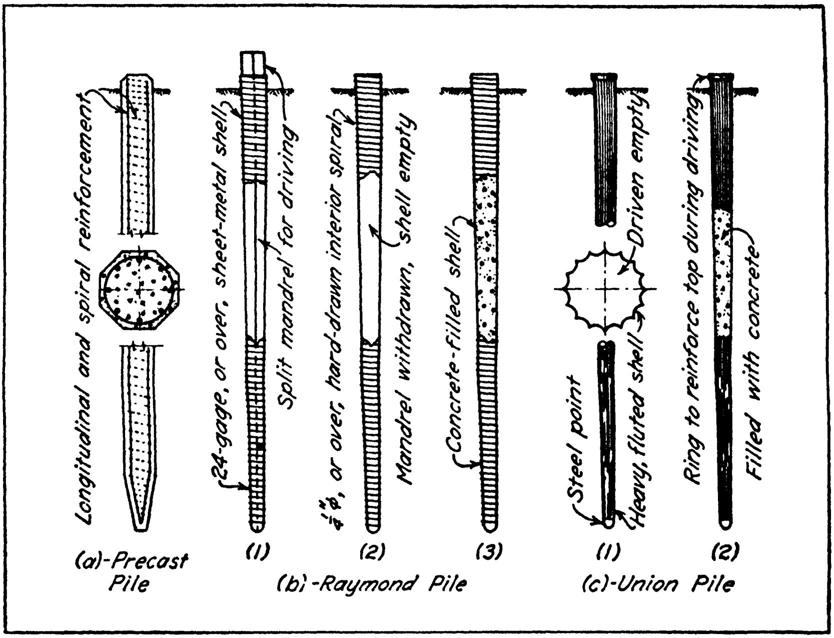


FIG. 31. Precast Concrete Pile and Cast-in-Place Shell Piles

core inside the shell and driving the mandrel and shell into the ground; (2) removing the mandrel and inspecting the interior of the shell; (3) filling the shell with concrete. For piles up to 40 ft. in length, the shell is in 8-ft. sections which lap over each other; and, for longer piles up to lengths exceeding 100 ft., the shell consists of sections screwed together at the joints. The *Union pile*, shown in Fig. 31*c*, is formed by: (1) driving a heavy sheet-steel, tapered shell into the ground and inspecting the interior; (2) filling with concrete. For piles up to 40 ft. in length, the shell is in one piece and for longer piles, up to 100 ft. or more, sections are welded together at the factory or in the field. The *MacArthur cased pile* is formed by: (1) driving into the ground a heavy steel casing with an inserted core; (2) removing the core and inspecting

the casing; (3) inserting a corrugated steel shell; (4) filling the shell with concrete; (5) placing the core on top of the concrete and withdrawing the casing leaving the concrete-filled shell in the ground.

A *shell-less pile* is formed by: (1) driving into the ground a shell with an inserted core; (2) withdrawing the core; (3) filling the shell with concrete and withdrawing the shell. This type is illustrated by the *Simplex pile* in Fig. 32*a* and by the *Pedestal pile* in Fig. 32*b*. The concrete in the Simplex pile is forced against the soil, as the casing is removed, by the fluid pressure of the concrete and by impact during placing. Greater pressure may be exerted, if desired, by tamping the concrete.

The *Pedestal pile*, shown in Fig. 32*b*, is formed by: (1) driving a casing and core into the ground; (2) removing core and placing concrete in bottom of casing; (3) replacing core and pulling casing up 1½ to 3 ft. while exerting pressure on concrete with core; (4) ramming concrete to form pedestal; (5) removing core, filling casing with concrete, replacing core to exert pressure on concrete, and pulling casing to form the finished pile.

Composite Piles. Wood piles and cast-in-place concrete piles are combined to form composite piles, as shown in Fig. 32*c*, in order to take advantage of the lower cost of wood pile for the portion below the ground-water level and in order to take advantage of the durability of concrete piles for the upper portion. If the Raymond pile is to be used, a wood pile is first driven nearly its full length into the ground. The shell and mandrel are then placed on the top of the wood pile and driven. The mandrel is removed and the shell filled with concrete, forming a concrete pile on top of a wood pile. The joint must be designed to stand driving and to exclude water and soil, and also designed so that the two sections will not separate from heaving of the soil when adjacent piles are driven. If the MacArthur cased pile is used, the wood pile is driven inside the casing and the concrete pile is then formed in the usual manner.

Pipe Piles. Piles of this type consist of heavy steel pipe filled with concrete, as shown in Fig. 33*a*. Pipes are driven with open ends. The usual types of pile hammers are used or hydraulic jacks are used when there is a load to jack against, as in underpinning.[31] The hydraulic jack is desirable for use where the space is restricted and where the vibration or noise due to pile hammer is objectionable.

The resistance to penetration is reduced by cleaning out the piles as the driving progresses. This is particularly true for piles driven through sand, because the sand plugs the end of a pipe and the resistance offered is the same as though the end were closed. Cleaning out is

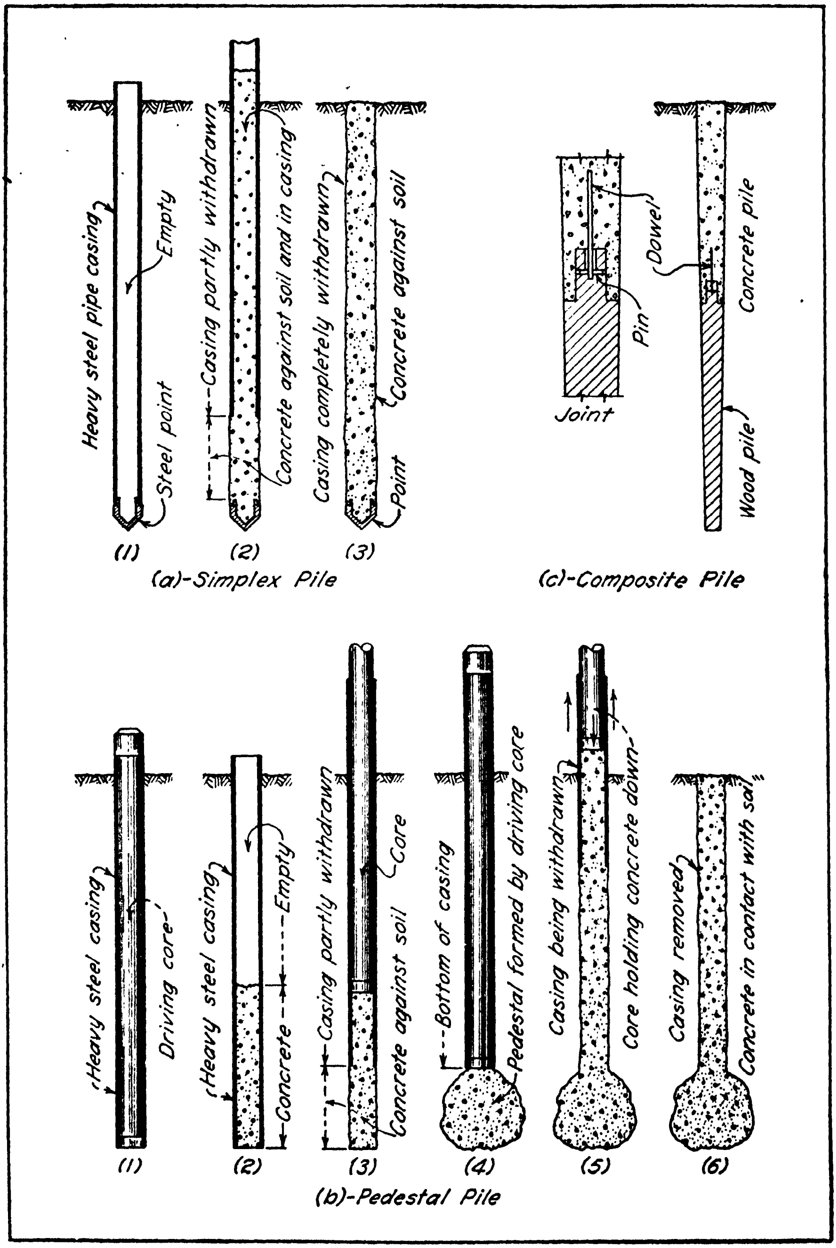


FIG. 32. Cast-in Place Shell-less Piles

usually done with compressed air. This is accomplished by pushing a pipe about 2½ in. in diameter down into the soil in the pipe and forcing air through it at a pressure approaching 100 lb. per sq. in. This air pressure blows the soil out of the pipe. Water may be mixed with the soil to facilitate its removal. Pipe piles are also cleaned with small orange-peel buckets and earth augurs.[31] Clay cores in pipe piles have

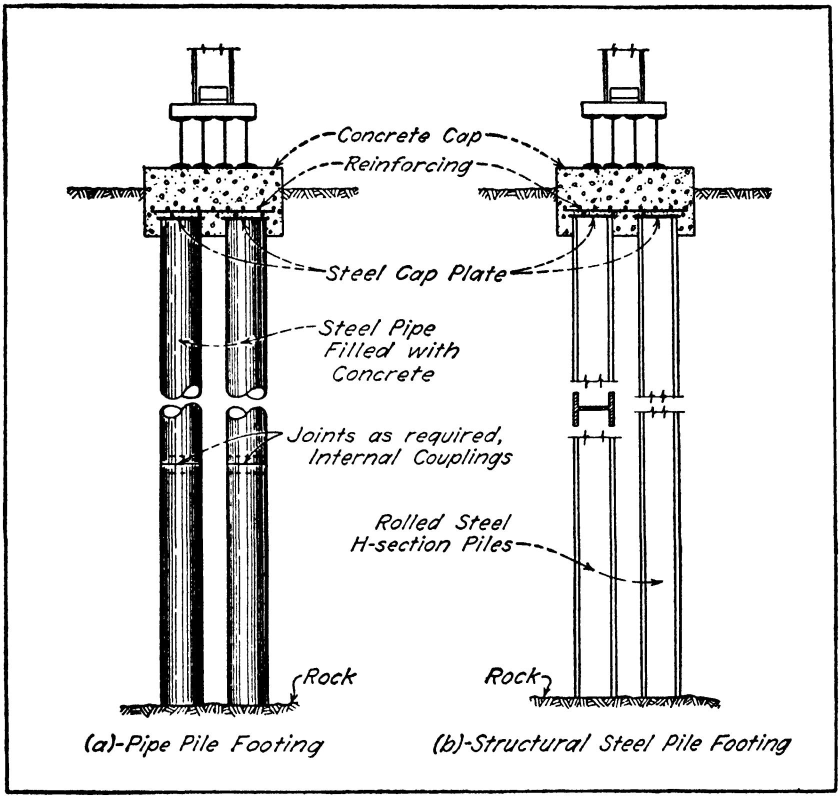


FIG. 33. Pipe Pile and Structural Steel Pile Footings

been removed by withdrawing the pipe and core, forcing the core out with a plunger, and redriving the pipe.[34] The pipes may be placed in sections with joints which will hold the sections in position, will insure good bearing between the ends of the sections, and will not project on the outside of the pipe. Concrete is placed by dumping at the top of the pile but the bottom portion of long piles should be placed with drop-bottom buckets to avoid segregation. Water should be removed from the pipe before the concrete is placed, but if this is not possible

the bottom can be sealed with concrete placed with a drop-bottom bucket. After this seal has set, the water can be pumped out and the remainder of the concrete placed in the dry. After the concrete is set, a steel plate may be grouted over the upper end of the pile to secure good bearing on the steel and the concrete. In determining the bearing capacity of pipe piles, both the steel and concrete are considered as carrying stress, due allowance being made for the different moduli of elasticity of the two materials. The pipes are commonly $\frac{3}{8}$ in. thick, but thinner and thicker pipes are used. The diameters vary from 10 in. upward. In strength calculations, a deduction of $\frac{1}{16}$ in. is made in the thickness of the pipe to allow for corrosion. Available information indicates that this allowance is ample for any expected life of a building.[31,36]

Structural-Steel Piles. Rolled-steel H sections, as illustrated in Fig. 33*b*, have been increasingly used for bearing piles during recent years. This type of pile is particularly advantageous for use in driving to bearing on sound rock through ground where driving is difficult because of the presence of boulders or thin strata of hardpan or rock which are underlaid with weaker strata and therefore do not have adequate bearing capacity.[33] Because of their small sectional area, piles of this type displace only a small volume of soil, and are not effective in increasing the bearing power of loose sands by compaction. Also, they are not economical for use as ordinary friction piles because they are relatively expensive. Moreover, the full surface area is not available for frictional resistance because soil becomes wedged between the flanges and causes the pile to act as a square pile. Various methods have been used to a limited extent to increase the displacement due to a steel pile. One method consists of timber lagging bolted to the web or flanges, and another is to box the sections in by welding steel plates between the flanges.[33] Available information indicates that corrosion is not a serious factor in piles of this type and that an allowance of $\frac{1}{16}$ in. around the pile surface for corrosion should be ample.[33]

Comparison of Types. Wood piles should only be used where they will be below the permanent ground-water level, but concrete and steel piles do not have this limitation. A considerable reduction in excavation, masonry, and load to be carried may sometimes be accomplished by the use of concrete piles, as illustrated in Fig. 34*a*, because of the requirement that wood piles be below the permanent ground-water level.

Precast concrete piles are usually more suitable than cast-in-place piles for use where the piles project above the ground surface, although the shell type can be reinforced longitudinally and give satisfactory service under these conditions. Cast-in-place concrete piles are more

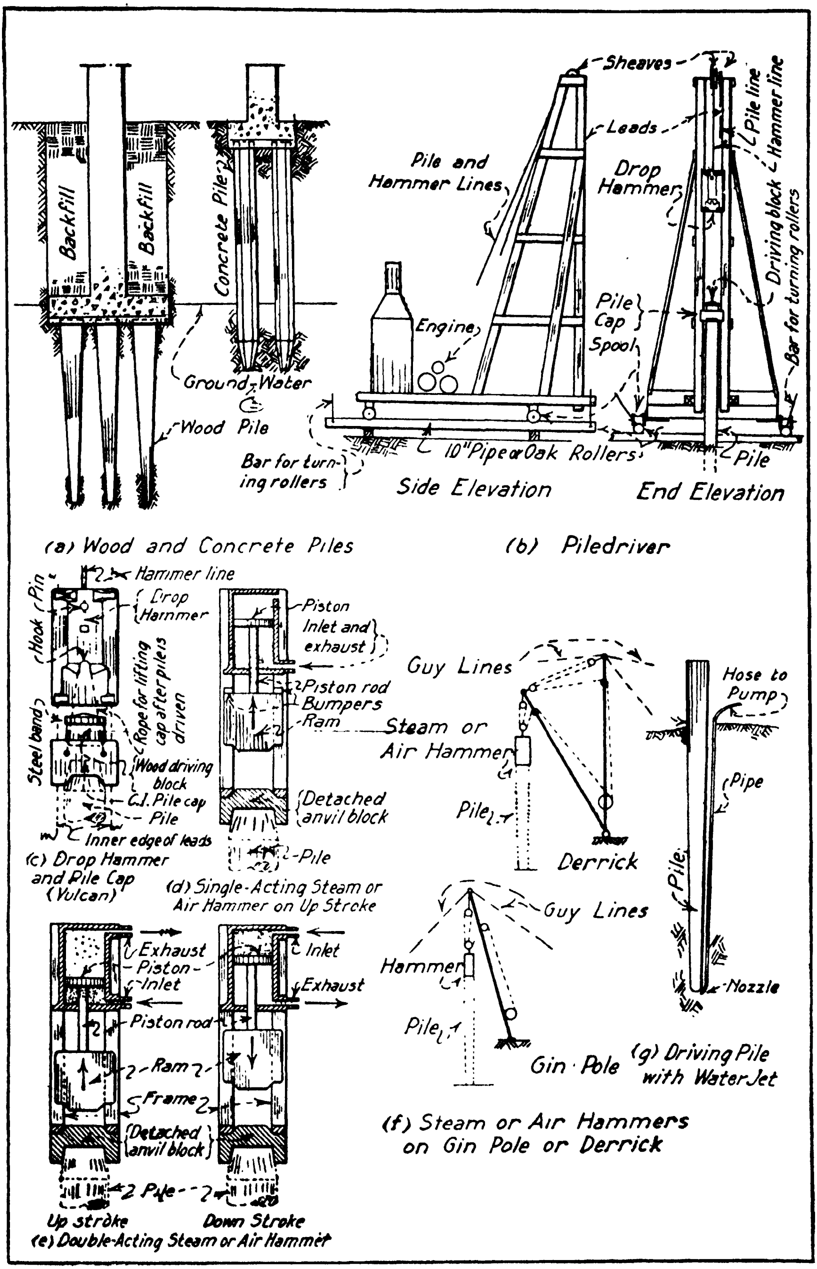


FIG. 34. Piles and Pile Driving

commonly used for foundations of buildings than precast piles. Precast piles must be reinforced to withstand the flexual stresses which occur during handling and the stresses due to driving; but the stresses are usually compressive, after the piles are in the ground, and do not require reinforcing. However, tensile stresses may be induced in piles by the heaving of the soil brought about by the driving of adjacent piles.[34] This may cause the rupture of shell-less cast-in-place piles. The rebound of the soil and the driving of adjacent piles may reduce the section or otherwise may injure shell-less cast-in-place piles before the concrete has set. The driving of adjacent piles may collapse the shells of shell-type cast-in-place piles[35] before the concrete is placed or may injure the piles themselves immediately after placing the concrete. To avoid injury to cast-in-place piles by the driving operations for adjacent piles, it is commonly required that all the shells or removable casings for a group of piles be driven before placing the concrete in any of them,[30] or at least that any pile not be poured which is to be within 5 ft. of a pile which is to be driven.[35] The shell-type cast-in-place pile excludes water and earth from contact with the fresh concrete of the pile. The required length of precast piles must be determined before they are ordered. They must be cut off in the field and the excess length wasted if they can not be driven to the ordered depth. The withdrawing of the casing in forming shell-less cast-in-place piles, or encased piles in which the shell is inserted in the casing before withdrawal, releases the stresses set up on the soil during driving and makes any dynamic pile-driving formula inapplicable.

Pipe piles and structural-steel piles are usually carried to rock, or at least to hardpan, to develop their carrying capacity, and they are usually used to carry heavy loads. Structural-steel piles can penetrate hard strata and gravel. Apparently the corrosion of the steel of pipe piles or of structural-steel piles is not an important consideration except under unusual conditions.[31,33]

The allowable load on individual piles varies from 15 tons to 150 tons, depending upon the type of pile, the supporting material, and other factors. The minimum value is for a wood-friction pile and the maximum value for a 22-in. steel-pipe pile bearing on rock.[37] Of course, larger loads can be carried by steel-encased concrete cylinders, constructed in the same way as pipe piles; but cylinders with 24 in. or larger diameters are classed as *piers* by the New York Building Code.

The cost of piles in place is commonly given per lineal foot. It varies with the type of pile, the soil conditions, local material, labor prices, and many other factors, but ranges from a minimum of 75 cents for wood piles to a maximum of $7.50 for pipe piles.[37]

As would be expected, the cost increases approximately at the same rate as the carrying capacity, although the conditions in any particular instance may make one type of pile the most desirable or other types impossible.

Almost any type of pile can be secured or constructed in lengths exceeding 100 ft. Pipe piles have been used in lengths as great as 140 ft.[36] Structural-steel H section piles 194 ft. long were used on the Potomac River Bridge at Ludlow Ferry, Maryland.

Further comparisons are made in the following article.

Pile Driving. Wood piles and precast concrete piles may be driven by means of a pile driver, as shown in Fig. 34*b*, operating in conjunction with a drop hammer, a steam hammer, a pneumatic hammer, or a water jet.

When using a drop hammer, the pile is lifted into vertical position by the pile driver. A heavy weight called a *drop hammer,* shown in Fig. 34*c,* is then dropped on the head of the pile, driving it into the ground, the weight being guided in its fall by the *leads* of the pile driver. The hammer is raised by a steam engine, a gasoline engine, or an electric motor, and the process is repeated until the desired penetration has been secured.

The *steam hammer* is extensively used instead of the drop hammer for driving. It rests on the head of the pile all the time while driving, its driving power being derived from the reciprocating parts of the hammer itself which strike relatively light blows in such rapid succession that the pile is kept in continuous motion. Steam hammers are of the single-acting and the double-acting type. A *single-acting steam hammer* consists of a heavy ram which is raised 2 to 4 ft. by admitting steam under pressure to a cylinder located above the ram and which falls by gravity when the steam is exhausted. The steam pressure acts against the under side of a piston in the cylinder, and the piston is connected to the ram by a piston rod. The ram is guided in its fall, and the various parts are held together by a frame, as shown in Fig. 34*d.* The hammer is placed in position on top of the pile by using a pile driver or by suspending it from the boom of a derrick or from a gin pole, as shown in Fig. 34*f.* A *double-acting steam hammer* is similar to a single-acting hammer. The ram is raised 4 to 20 in. by steam admitted under pressure to the cylinder on the lower side of the piston, but instead of falling by gravity alone, as in the single-acting hammer, the ram is forced down by steam under pressure admitted to the cylinder on the upper side of the piston at the same time as the steam on the lower side is exhausted. The principle of the double-acting hammer is shown in Fig. 34*e*.

Special devices are used for protecting the heads of concrete piles

during driving and to fit over the heads of sheet piles. The weights of steam hammers vary from 100 lb. to 16,000 or 18,000 lb. to meet the varying requirements. The light hammers are designed for a man to operate, without a pile driver, derrick, or block and tackle, in driving sheathing. Steam hammers may be operated with compressed air as *pneumatic hammers*. Some types may be arranged to operate under water. Steam hammers may be inverted for use in pulling sheet piles and sheathing. Steam hammers drive piles more rapidly than drop hammers and injure them less.

The *water jet* is extensively used in driving piles. It consists of a pipe placed at the side of a pile, as shown in Fig. 34*g*, through which water is forced, washing the material away from the point of the pipe. The pile drops into the space formed by the water jet. Some water from the jet rises to the surface along the sides of the pile and acts as a lubricant in decreasing the friction of the surrounding earth, thus assisting materially in driving. A load may be placed on the pile to assist in forcing it down, or else light blows may be struck with a pile hammer. In addition to the jet which delivers water to the point of the pile, jets may be used to deliver water along the side of the pile to assist in decreasing the frictional resistance. After the driving by the jet is completed the earth settles around the pile and develops frictional resistance to correspond with that developed in driving without the jet. The final penetration is usually given with a pile hammer after the jet has been turned off.

The pipe used in jetting is about 2½ in. in diameter, with the lower end decreasing in diameter to 1½ in. to form a nozzle. The upper end of the pipe is connected to a force pump by means of a hose. Concrete piles often have the jet pipe cast in place along the axis of the pile. Piles driven with a water jet are not injured in driving; so this method is particularly suitable for precast concrete piles. The water jet may be used in many classes of material, but it operates most successfully in sand. Many building codes do not permit the use of the water jet except by special permission.

The pipe for pipe piles used in underpinning is often forced into position by *hydraulic jacks* which act against the building. This operation requires less space than a pile driver and causes less disturbance.[31]

ARTICLE 20. BEARING POWER AND SETTLEMENT OF PILE FOUNDATIONS

General Discussion. For the sake of convenience, it is commonly stated that piles are used to support foundations. However, it must be kept in mind that piles are intermediate members which transmit foun-

dation loads to the underlying soil of rock. Piles used in this manner are called *bearing piles* to distinguish them from *sheet piles* and other kinds of piles, such as *fender piles* and *guide piles*. Sheet piles are driven close together to form a continuous barrier or sheet which will retain earth or to form a water-tight diaphragm. Fender piles and guide piles have special uses, as indicated by their names.

In Art. 13 and in Fig. 15, the use of bearing piles in connection with foundations was mentioned and illustrated. Types of piles and pile foundations are considered in Art. 19. The soil into which the piles are driven may be fairly uniform throughout the length of the piles, so far as bearing capacity is concerned, as shown in Fig. 15*c*, in which case the load is transmitted from the pile to the surrounding soil; the piles may penetrate through soft soil with little or no bearing power into firmer soil, to which the load is transmitted by the piles, as shown in Fig. 15*d*; or the piles may penetrate through soft soil to hardpan or rock, to which the load is transmitted by the ends of the piles, as shown in Fig. 15*e*. The entire load on a pile foundation is considered as transmitted through the piles with no load transmitted directly to the soil by the pile cap.[67]

Piles must be strong enough to withstand handling and driving and to carry the loads transmitted to them by the foundation. The bearing strength of the end of a pile resting on rock or hardpan, and the bearing strength of the rock or hardpan must be adequate.

Causes of Settlement. The settlement of pile foundations supported on rock or hardpan is negligible, but foundations supported by soil will always settle. The objective in design and construction of pile foundations, as in spread foundations, is to keep the total settlement from being excessive and to restrict the differential settlements between different parts of the structure to amounts which will not induce excessive stresses or deformations in the structure. Values of total settlement and of differential settlement which will be considered excessive in any case depend upon location, type of construction, and other factors.

The causes of settlement of pile foundations may be listed as follows:

(1) An individual pile may fail by moving excessively through the soil which surrounds it, as shown in Fig. 35*a*, or it may fail by excessive stresses in the pile itself. The normal action of an individual pile is to settle because of the consolidation of the surrounding soil to which it transmits stress, as indicated by the bulb of pressure in Fig. 35*b*. However, piles are not used individually.

(2) A group cluster of piles supporting a footing, together with the enclosed soil, may fail by yielding as a unit, and then move downward in relation to the soil which surrounds it, as shown in Fig. 35*c*.

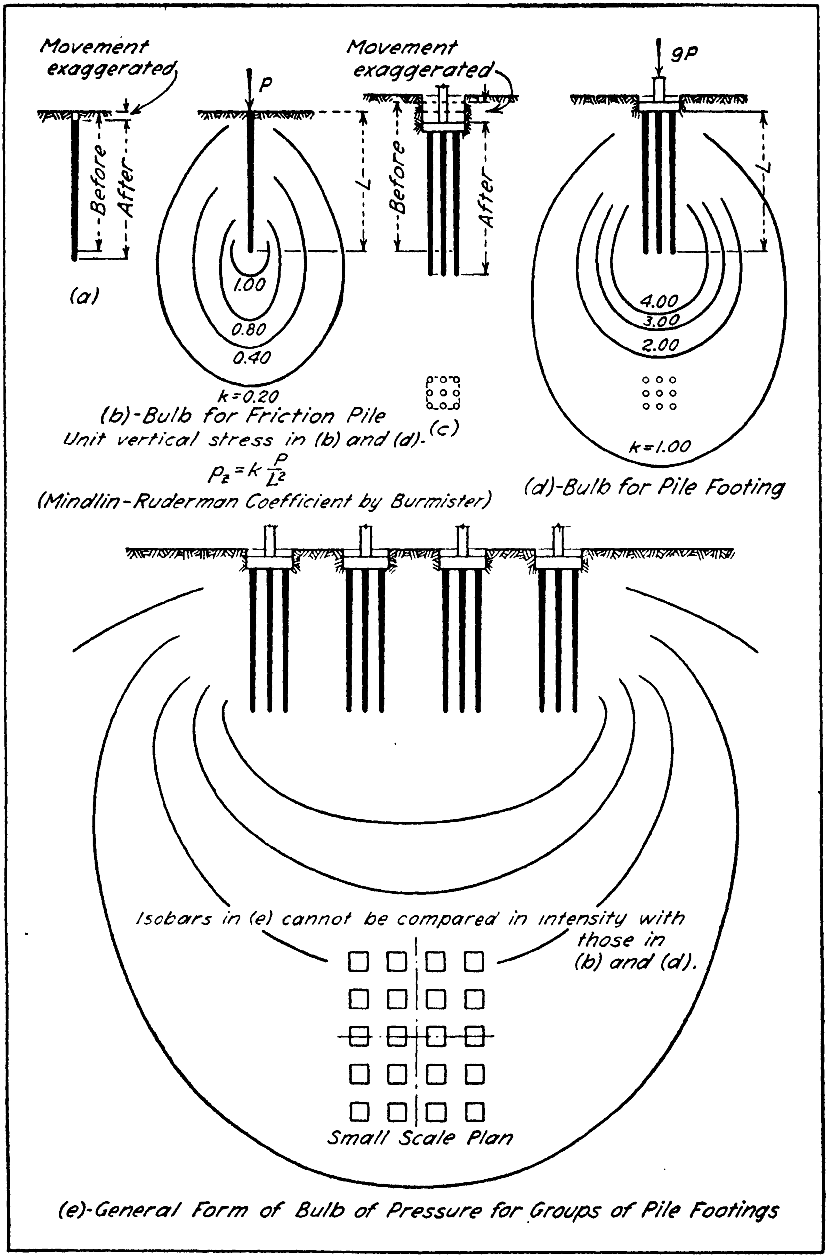


FIG. 35. Bulbs or Pressure and Settlement of Piles and Pile Footings

(3) A pile footing and the soil which surrounds it will always settle because of the consolidation of the soil to which the foundation load is transmitted by the piles, as shown by the bulb of pressure in Fig. 35*d*.

(4) An entire pile foundation, consisting of several pile footings, will settle because of the consolidation of the soil underlying the structure as a whole. This condition is the normal one for building foundations consisting of a number of isolated footings; but unexpected settlements of large magnitude may be caused by layers of soil, such as peat, with low bearing power, whose presence was unknown because of inadequate subsurface exploration. To make sure that this difficulty is not encountered, the soil should be investigated for a considerable distance below the tips of the piles. The total settlement of a footing is due to the consolidation of the soil, resulting from the stresses transmitted to it by the piles, as indicated by the bulb of pressure in Fig. 35*e*.

Other causes of settlement are the lateral movement of the soil under a foundation because of excessive loads, removal of lateral support or undermining, compacting of the soil by vibrations, and the injury of piles during driving.

Before settlement due to consolidation can take place, the stresses in the soil must be large enough to break the bond between the clay grains as mentioned in Art. 18.

Pile Action. Unless resting on hardpan or rock, a pile is supported by *skin friction* along its length and *point resistance* at its lower end, exerted by the soil which surrounds the pile. A pile supported primarily by skin friction is called a *friction pile* or a *floating pile*, and one which is supported primarily by point resistance, a *point-bearing pile*. The distribution of the load between skin friction and point resistance depends upon the type of soil penetrated, and is discussed in a subsequent paragraph. Below the point of the pile, the load is, of course, carried entirely by the underlying soil. A pile, therefore, increases the bearing power of an area by distributing the load over a wider area and deeper into the soil. The pressure distributions due to a plate or footing on the ground surface, a friction pile, and one which transmits its load primarily by point resistance, are illustrated in Fig. 36.

The form of pressure bulb for a loaded area is fairly well established. The form of pressure bulb for a pile, however, can be shown only diagrammatically because adequate information is not yet available. Such solutions as have been proposed[63] do not seem to be entirely consistent.

Piles driven in deposits of loose sand compact the sand and thereby increase its bearing power. When this has been accomplished to the degree desired, the piles have served their purpose.

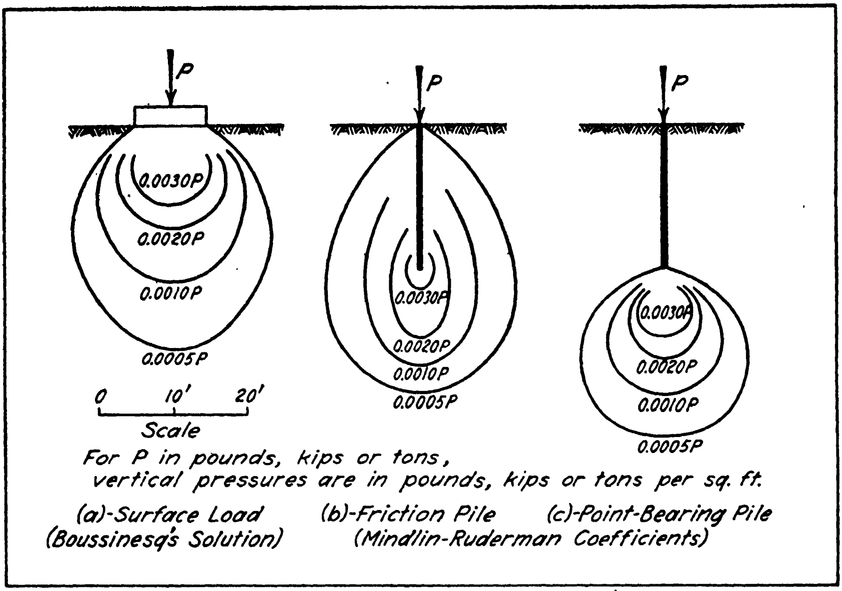


FIG. 36. Comparison of Bulbs of Pressure

Pile Clusters or Groups. Piles are not used singly but are arranged in groups or clusters centered under the loads to be carried, these loads being distributed to the individual piles by rigid *pile caps*, which are usually of reinforced concrete and are similar to spread footings. A footing bearing on piles is called a *pile footing.*

It is commonly assumed that the bearing power of a group of piles is equal to the bearing power of one pile multiplied by the number of piles. This is true when the piles rest on rock or if the piles are spaced so far apart that the overlapping of the pressure bulbs is of no consequence. Piles which depend primarily on point resistance can be spaced more closely than friction piles, the controlling factors in this form being the compressive strength of the piles and the bearing capacity of the layer into which they are driven or on which they bear.

There is no satisfactory criterion for the spacing of friction piles. It is sometimes considered that the circumference of the group of piles should at least equal the sum of the circumferences of the individual piles. This is based on the assumption that the shearing resistance per unit of surface area is the same for the piles as for the prism of earth included within the circumference of the pile group,[40,57] as shown in Fig. 35*c*. This requirement results in wider spacings than are normally used. The center-to-center spacing of piles is commonly required to be

not less than twice the diameter of round piles or the diagonal of rectangular piles, but the minimum of 2 ft. 6 in. is often used.

The distribution of vertical pressures on a horizontal plane at the points of the piles is probably as shown in Fig. 37.[29] In this figure it is assumed that the piles act independently and that the total vertical pressure at any point on the horizontal plane is equal to the sum of

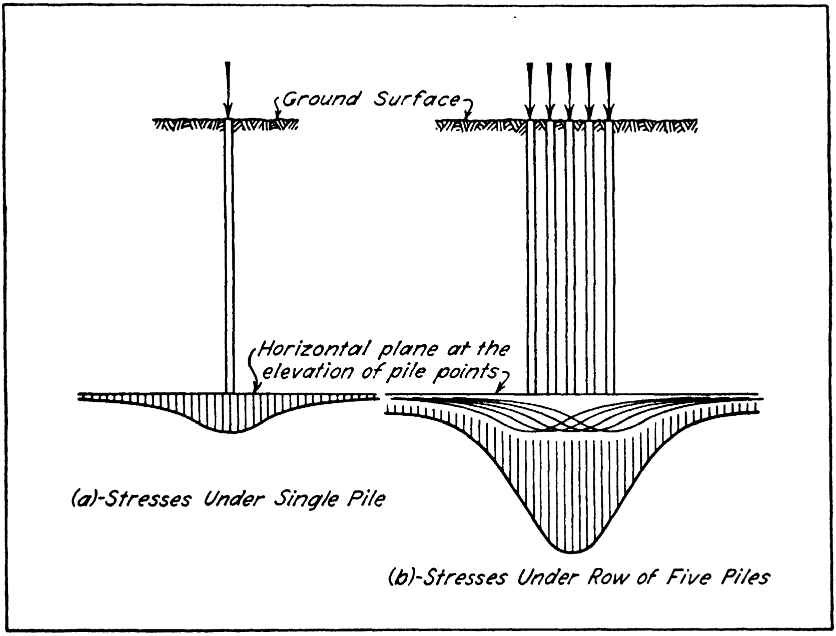


FIG. 37. Vertical Pressure Distributions at Elevation of Pile Points[29]

the vertical pressure at that point due to the individual piles. On this basis, the settlements of the center piles would obviously be greater than those of the outside piles. However, clusters of piles are always capped with a rigid cap which would cause all the piles to settle nearly the same amount. This would tend to increase the pressure under the outer piles and decrease it under the center pile, but the pressure under each center pile would still be greater than under a single pile.[29]

A simple procedure that has been proposed assumes that the load from a group of piles is distributed outward and downward, at an angle of 60 deg. with the horizontal, from the perimeter of the group of piles at the elevation where the piles enter a stratum with satisfactory bearing capacity. The soil pressures are considered uniformly distributed on the portions of horizontal planes included within the 60-deg.

limiting planes. This procedure is illustrated in Fig. 38. Each pile is assumed to carry by point resistance a load equal to the allowable unit bearing pressure of the soil at the point of the pile multiplied by the area of the point. The remainder of the load is assumed to be carried by skin friction and to be transmitted to the surrounding soil at a uniform rate along the length of the pile between the elevations A–A and

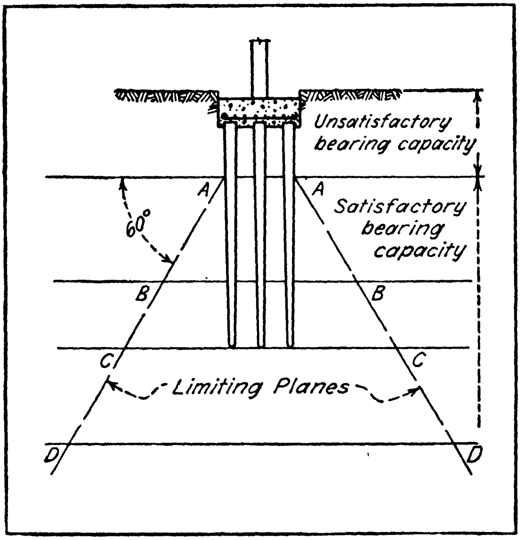


FIG. 38. Assumed Distribution of Vertical Pressures under Pile Footing

C–C. On this basis, the unit bearing pressure at elevation B–B is equal to the load carried by skin friction divided by the area between the 60-deg. planes minus the area of the piles. The unit bearing pressure at elevation C–C, or just below the points of the piles, or the elevation D–D at some distance below C–C, is equal to the total foundation load divided by the area at C–C or at D–D. The actual bearing pressures at the depths where the soil type changes are computed in this manner and compared with the allowable bearing pressures, given by the code being followed, for these soils. These allowable pressures must not be exceeded. Only the pressures due to the foundation load are included. Overlap of planes of adjacent footings must be considered.

If the bearing capacity of a footing, as determined by this procedure, is found to be inadequate, it may be increased, as shown in Fig. 39, by increasing the size of the footing or by increasing the length of the piles, assuming that there is no change in the allowable unit bearing pressure on the soil because of change in nature of the supporting soil.

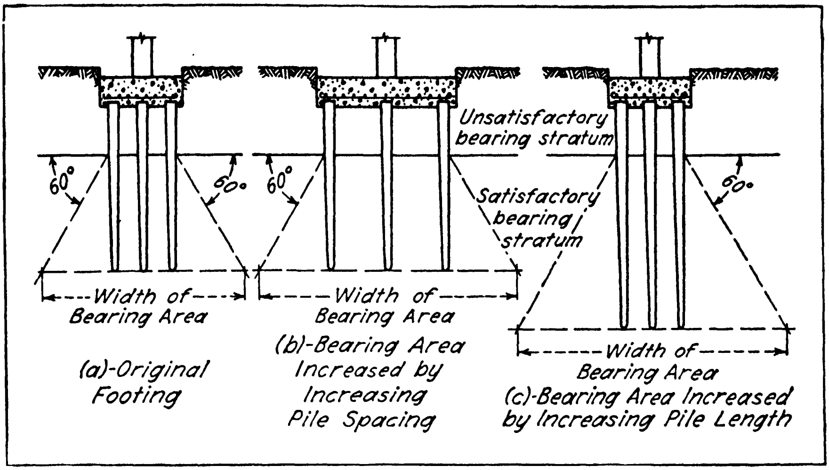


Fig. 39. Methods of Increasing Bearing Power of Pile Footing

Effect of Width of Pile Foundations. Bulbs of pressure for a spread footing are compared with those for a pile footing in Fig. 40*a*, where the halves of each type are shown in adjacent positions. It is seen that the piles serve to transmit the pressure deeper into the soil. A comparison of the bulbs of pressure for a mat foundation supported directly on the soil and for a mat foundation supported on piles is shown by the half-sections in Fig. 40*b*. It is seen that the piles have little relative effect in lowering the bulb of pressure where the foundation is wide in comparison with the length of the piles. These conditions were discussed by Terzaghi in his paper, "Science of Foundations,"[20] from which Fig. 40 was taken. His conclusions are:

If the length of piles is at least equal to the width of base, their effect is obviously very beneficial (Fig. 40*a*). The piles reduce the intensity of maximum pressure acting on the ground, and, in addition, they shift the zone of maximum stress from the surface to the level where the lower ends are located. Since the effect of the depth of foundation on the bearing capacity of the ground depends not on the depth but on the ratio between the depth of foundation and its width, the effect of transferring the pressure to a deeper level, in the case of Fig. 40*a*, may be very important. On the other hand, if the width of the foundation is considerably greater than the length of the piles, the pressure-reducing effect of the piles is very small and the ratio between the depth of foundation and the width of the structure is also very much smaller than in the case of Fig. 40*a*. Hence, the beneficial effect of the piles may be negligible and the money invested in them may represent an unwarranted expenditure.

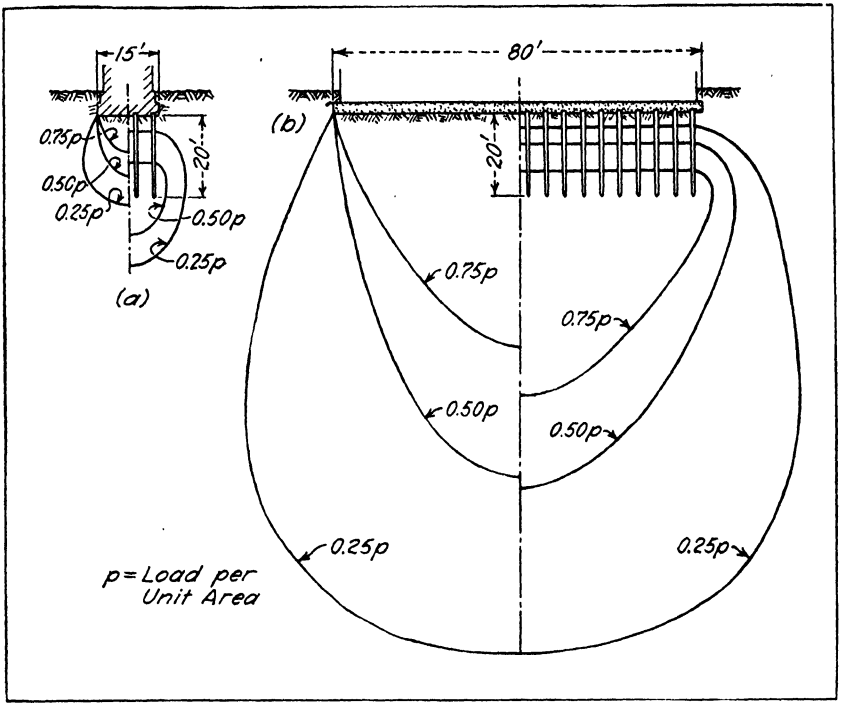


FIG. 40. Relation between Width of Foundation and Effectiveness of Piles

Effects of Type of Soil. When a pile is driven into soil it occupies space. That space can be made available only by compressing the surrounding soil or by displacing the volume of soil equal to the space occupied by the pile. In the latter case, the only way the soil can move to compensate for the volume displaced by the pile is upward so that the surface of the soil surrounding the pile rises or *heaves*. In some soils, the space occupied by the pile may result partially from compression and partially from heaving. The action of soils during the pile-driving operation is well expressed by J. Stuart Crandall,[39] as follows:

The voids of clays and silts are usually filled with water and, being relatively impermeable, cannot be compressed during the short period of pile driving so that the soil must be displaced an amount equivalent to the volume of the embedded piles resulting in *heaving*. In compact sands and gravels, piles cannot be driven without displacing the soil, causing heaving, either by the driving process alone or with the aid of jetting. In loose sands, gravels, and fills, the action of driving tends to rearrange the soil particles into a more compact structure. This may result in some subsidence of the surface which

would depend on the degree of volume change by reason of the reduction in voids. Where layers of several kinds of soil are penetrated, a combination of these effects may take place.

The bearing power of loose sand or other compressible fill may be improved by compacting it by means of piles. The spacing of piles required to produce the required bearing power by compaction is determined by trial. Advantage is taken of the compacting effect of piles in loose sand or in other compressible soil when *sand piles* are used. When sand piles are used, a hole is formed in the sand by driving and withdrawing a pile or by some other method. The hole thus formed is gradually filled with sand which is thoroughly tamped during the operation. The tamping of the sand enlarges the hole in which it is placed and thereby further compacts the surrounding sand. Sand piles are rarely, if ever, used in this country.

It may be difficult or impossible to drive piles into dense sand or gravel without the aid of a water jet's acting at the point to decrease the point resistance and, in some instances, along the length of the pile to decrease the frictional resistance. The jet washes the sand grains away from the point of the pile and up along its surface to the top of the ground. If a jet is used, the final penetration of the pile should be secured by driving with the hammer only. Jets are not effective in clay soils. If the usual heaving of such soils must be reduced because of its effect on adjacent piles, or for other reasons, holes may be bored to receive the piles which are driven into final positions, the depth of the holes being less than the length of the piles.[47,48]

When driving a pile into clay, the vibration of the pile tends to *remold* the clay immediately surrounding the pile by changing its structure, as explained in Art. 12. Remolding breaks the bond between grains and greatly increases a soil's compressibility. The remolded clay may gradually settle by consolidation under its own weight, with a resultant settlement of the foundation. If this actually occurs, the use of piles would increase rather than decrease the settlement.[9] However, this remolding phenomenon is not considered, by all foundation engineers, as contributing to settlement.[29,40] The point resistance of piles driven in clay does not exceed 20 per cent of the total load at failure, and for safe loads the entire pressure is transmitted by skin friction.[9] Point resistance is an important factor in the bearing capacity of piles driven into sand.

When piles are driven through a layer of partially consolidated soil and into firm soil, the load on the piles may be gradually increased as the layer consolidates and settles.[39] This increase is caused by the frictional drag on the piles as the settlement progresses and may result in increased settlement of the foundation or failure of the piles.

The bearing power of a pile may increase or decrease after the driving is completed. If the pile is driven into coarse sand which can drain freely, there is little change after a period of rest. In fine sand and silt, which are less permeable than the coarse sands, and in clay, the displacement of soil by the pile will build up pressure in the water in the voids of the soil surrounding the pile. This pressure resists the penetration and increases the point resistance. However, since the soil is slowly permeable, this water pressure will gradually be dissipated and the point resistance will decrease accordingly. Piles driven into clay displace the corresponding volume of clay, causing heaving, and compressing the clay very little. However, a small amount of water is squeezed out of the clay adjacent to the pile point and rises around the pile. This lubricates the surface of the pile and reduces its frictional resistance. The vibration of the pile during driving makes the hole slightly larger than the pile and forms a space around the pile into which the water can flow. After driving, the clay surrounding the pile gradually reabsorbs the water and " sets " around the pile, thereby increasing the skin friction. Since most of the bearing power of piles driven in clay is due to skin friction, this increase in skin friction, after a period of rest, increases the bearing power.[20]

Except in clean sands and gravels, the adhesion between the soil and a pile is usually greater than the shearing strength of the soil itself, so that the resistance along the sides of a pile is usually the shearing strength of the soil immediately surrounding the pile.[20] This shearing resistance depends upon the internal friction and the cohesive strength of the soil. Because of the compacting effect of the pile during driving, the shearing strength of the soil close to the pile may be greater than that of the soil at some distance from the pile. The shearing area, of course, increases as the distance from the pile increases.

The order in which the piles of a cluster should be driven depends upon the nature of the soil into which they are driven. In soils which heave, it is usually preferable to drive the inner pile first and progress outward in order to distribute the heaving effect. If piles are driven for the purpose of compacting deposit of loose sand or other easily consolidated material, and thereby for increasing its density and bearing power, the most effective results can be secured by driving the outer ring of piles first and progressing inward. By driving in this order, the sand is more closely confined during the driving operation, and the compressive effect resulting from the soil displaced by the piles is most effective. These accumulative outward or inward effects may be reduced, if desired, by driving the piles in such an order that the first piles driven will be widely spaced, the intermediate piles being driven later.

Bearing Power of Individual Piles. The bearing power of individual piles is computed by means of pile formulas or measured by applying loads to *test piles*. The formulas used may be of the static or the dynamic type. These formulas refer to the resistance offered by a pile to loads which tend to cause it to move or slip in relation to the soil which immediately surrounds it, and not to the bearing power of the surrounding soil. Settlement of the pile may be due to movement of the pile with reference to the soil or to the movement of the pile and the surrounding soil, as a unit, because of the consolidation of the soil under the action of the pressures induced in it by the load transmitted from the pile to the soil.

Static formulas estimate the bearing power by computing the frictional resistance along the surface of the pile and the bearing resistance of the point. The frictional resistance and the point resistance are obtained experimentally, or the frictional resistance is computed by multiplying the computed pressure of the earth on the pile surface by the coefficient of friction of the earth on the pile or of earth on earth — whichever is the smaller — the pressure being computed by earth pressure theory. In the latter case the point resistance is also computed for earth-pressure theory.[41,42,69] Because of the extreme variation in soils of the same general class, it is difficult to determine suitable values for the pertinent properties to use in computing frictional and bearing resistance. However, Cummings is of the opinion that:

> The study of the carrying capacity of piles on the basis of purely static considerations is one of the most fertile fields for research in the whole subject of pile foundations.[29]

Dynamic formulas are used to compute the bearing power of a pile from its behavior during driving. The factors used in all formulas are the energy used in driving, as determined from the product of the weight of the hammer and the vertical distance through which it moves before striking the pile, and the average penetration produced by the last few blows. Other factors which may be included are the weight of the pile, its cross-sectional area, its length, and the modulus of elasticity of the material of which it is composed. These factors are used to compute the energy which is lost during impact of the hammer on the pile and is, therefore, not available to produce penetration.

The formula most commonly used in this country is the *Engineering-News* formula which is as follows:

$$P = \frac{2Wh}{s + c}$$

where P = the allowable load on the pile; W is the weight of a drop

hammer, or the weight of the moving parts of a single-acting steam or air hammer; h is the distance through which a drop hammer falls or the stroke of a steam or air hammer, expressed in feet; s is the penetration for the last blow or, more commonly, the average penetration for the last few blows, expressed in inches; and c is a constant equal to 1.0 for a drop hammer and 0.1 for a steam or air hammer. The values for P and W are expressed in the same units, either in pounds or tons. The product Wh is the energy exerted by the hammer in striking one blow. The ram of the single-acting hammer is raised by pressure but drops under the action of gravity only, as explained in Art. 19. When the double-acting hammer is used, the ram is forced down by steam pressure so that the product of the pressure and the area of the piston represents the force driving the ram which is added to the weight of the ram, and the weight of other moving parts, in determining the total force which acts through the distance, h, in striking the pile. The *Engineering-News* formula has the advantage of simplicity. Even though this formula is widely used, most engineers have little confidence in it.

The frictional resistance and the point resistance of a pile in permeable materials, such as sand, gravel, and permeable fills, are nearly the same during driving as under static load. When a pile is driven into such materials, a theoretically sound, dynamic formula can be expected to give good results. However, the frictional and point resistances which prevail during driving differ very greatly from those which act when a pile is at rest, if a pile is driven in relatively impermeable materials such as fine-grained silts and soft clays. As explained under the heading Effects of Type of Soil, skin friction in soils of this type is reduced during driving by water squeezed out of the soil, which lubricates the surface between the pile and the soil; and point resistance is increased by the pressure built up in the pore water as the point displaces the soil. After a period of rest, the water along the pile surface is absorbed by the soil and frictional resistance is restored, but the point resistance decreases because the excess water pressure at point is dissipated as water gradually moves from the region in which the pressure is built up by driving. In the words of Terzaghi:

> The application of any pile-driving formula to the bearing capacity of piles driven in the second class of materials is a gamble, trusting that the deficiency in skin friction associated with the driving of the pile may, by chance, be compensated by the corresponding excess in point resistance. Considering these facts, it seems futile to attempt any further improvements in the field of pile-driving formulas. For materials in the first class, the pile-driving formulas were good enough fifty years ago; while for material in the second class, no reliable pile-driving formulas are possible at all.[20]

In a paper, "Dynamic Pile Driving Formulas,"[43] A. E. Cummings discusses the defects in formulas of this type and states:

> In spite of all the effort that has been expended on the problem in the past, pile driving is not yet an exact science. At the present time, the installation of a satisfactory pile foundation is largely a matter of experience and good judgment combined with a careful soil investigation.

Dynamic pile-driving formulas are applied to cast-in-place piles. This may be logical when applied to shell piles where the shell is rigid enough to maintain the compression in the soil surrounding the pile. With shell-less piles, the conditions are changed so radically by removing the casing that such a formula is not a good indicator of bearing capacity.

The most satisfactory method for determining the bearing capacity of individual piles supported in soil is by actually loading piles and observing their behavior during driving and under static load. Such piles are called *test piles*. Enough test piles should be used to make certain that the variations in the soil conditions in different parts of the site are determined. A common requirement is that the allowable load on a pile shall not be greater than one-half the maximum load which causes no settlement for 24 hours, and the total settlement shall not exceed 0.01 in. for each ton of test load. Another requirement is that the design load shall not be greater than 50 per cent of the load which causes a permanent settlement of $\frac{1}{4}$ in. in 48 hours. Other modifications of this requirement are in use. To be of value, the test loads should not be applied immediately after the pile is driven, but sufficient time should elapse to enable the soil to adjust itself to static conditions and thereby avoid the temporary effects of driving on the frictional and point resistance, as explained under Effects of Type of Soil. The bearing capacity of a pile may increase after a period of rest if driven in some soils; may decrease if driven in others; and may not change at all. In driving a test pile, the penetration per blow, or the average penetration for several blows, at the conclusion of driving should be observed. When the penetration per blow of the other piles, driven in the same material, is equal to or less than the final penetration per blow of the test pile, then those piles can be assumed to have a bearing capacity at least equal to that of the test pile. In using the test pile as an index of the bearing capacities of other piles, the piles themselves, the kind of soil, the hammer, and the procedure used in driving the piles must be the same as those associated with the test pile. This comparison of the final penetrations of piles with that of the test pile is not usually followed, but it is a desirable one.

The procedure which has been described is satisfactory for determining the bearing power of individual piles as controlled by permissible settlement, but as has been explained, the bearing power of a group of friction piles is not usually equal to the bearing power of one pile multiplied by the number of piles, owing to the overlapping of their bulbs of pressure. Occasionally, groups of three or four piles may be loaded with test loads, but the cost of applying the necessary loads to pile groups is so large that groups of piles are not often tested. Any adjustment of the design load for the number of piles in a group is based on judgment, although at least one building code includes a formula for this purpose.[44]

Settlement Prediction. The procedure used in predicting settlement of pile foundations supported by clay is similar to that for spread foundations outlined briefly in Art. 18. The vertical pressures in the soil supporting the foundation are computed on the basis of Boussinesq's method. Representative undistributed samples of the soil are subjected to consolidation tests which give data concerning the amount that they are compressed when subjected to given pressures. By mathematical procedures, the total effect of the consolidation of all the soil under a building in producing settlement is predicted from the vertical pressures which exist and from the behavior of the samples. The presence of the piles complicates the situation in the region covered by the depth to the tips of the piles. Below that elevation the conditions are identical with those under a spread foundation. It is necessary only to include the soil to a depth of about twice the width of the entire foundation because, at greater depths, the soil pressures are so low that they have very little effect on the settlement, providing, of course, that there are no layers of peat or other soft soil at greater depths.

Formulas for the bearing power of piles can only give information concerning the loads which individual piles will carry without being moved through the soil which surrounds them. They give no data concerning settlement. A loading test gives data concerning the amount of settlement of an individual pile under a given load due to any movement of the pile with reference to the soil and to any consolidation of the soil surrounding the pile during the relatively short period covered by the test. Since clay consolidates very slowly, the total settlement of test piles driven in clay is not obtained from the tests. Also, because of the overlapping of the bulbs of pressure of the individual piles and of groups of piles to form the composite bulb of pressure for the entire foundation, as indicated in Fig. 35, the settlement of an individual test pile is not an index of the settlement of that

pile when it is under a foundation. The settlement of each pile is contributed to by the loads on adjacent piles because of the overlapping bulbs of pressure. As indicated by the depths of the significant bulbs of pressure, deep-lying strata which would have no effect on the settlement of individual piles or on individual pile footings, contribute to the settlement of the foundation as a whole.[45] This condition may be particularly significant if there are deep-lying layers of soil which yield excessively. The lack of effectiveness of friction piles in reducing the settlement of raft foundations has been explained hitherto. The same situation may prevail in buildings supported on several isolated, friction-pile footings. As stated by Terzaghi:[26]

> No simple relation can possibly exist between the result of a loading test on an individual pile and the settlement of a pile foundation although the piles get their bearing in a firm stratum of gravel.

Terzaghi cites cases in which the settlement has exceeded forty times the settlement of an individual pile carrying the same load during a loading test. Also, the common assumption that settlement will be uniform if all piles are equally loaded is not correct.

The settlement of buildings founded on sand or gravel is usually not large, and friction piles are not often used for these buildings except when the sand is not in a dense state and vibrations from machinery, etc., may cause the sand, and the building it supports, to settle. Any settlement which is to occur will take place within a relatively short period. Present methods for computing settlements are based on the theory of consolidation and apply only to soils such as clay in which the settlement is due to the squeezing of water out of the soil.[46] Settlement due to consolidation will take place only when the stresses are large enough to break the bond between the clay particles.[67]

ARTICLE 21. CONCRETE PIERS

Tall buildings are frequently supported on concrete piers carried to the depth required to reach a material such as firm clay, hardpan, or bed rock which will have the necessary bearing power, as shown in Fig. 15. Such buildings are always of steel or reinforced-concrete skeleton construction, wherein the foundations are called upon to support columns and not bearing walls. The column load is distributed over the pier by grillage beams or by rolled or cast-steel slabs frequently 6 in. and more in thickness. The top 2 or 3 ft. of such piers is commonly reinforced with steel spirals or hoops. If the height does not exceed twelve times the diameter or if the diameter is 6 ft. or over, reinforcement is not required, but special reinforcement is sometimes used to reduce the size. Piers whose height exceeds twelve diameters

and whose diameter is less than 6 ft., should be reinforced with a minimum of $\frac{3}{4}$ per cent vertical steel spaced uniformly around the pier about 3 in. from the surface.

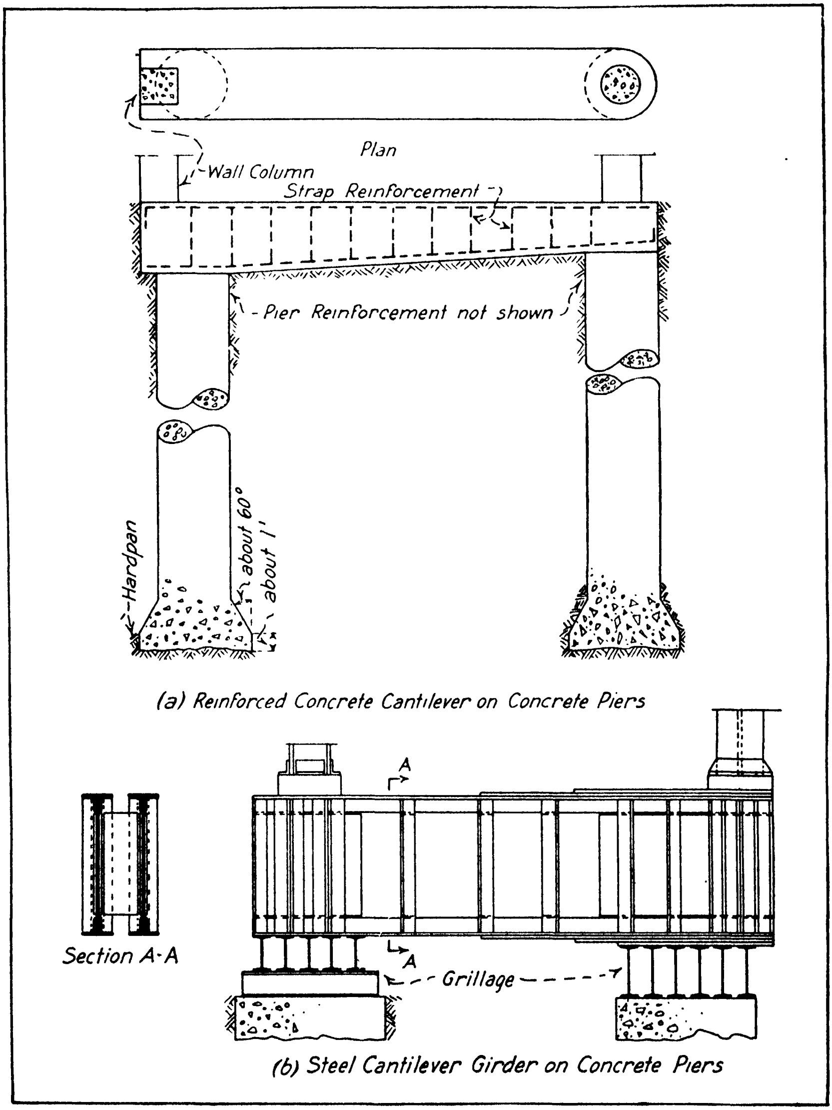


FIG. 41. Cantilevers on Concrete Piers

If a pier is to rest on bed rock which is at least as strong as the concrete, the uniform section shown in Fig. 15*h* is used. If the supporting

material is clay or hardpan, the bearing area must be greater than the, required area of the pier; therefore the pier is belled out, as shown in Fig. 15*g*, in soils such as firm clay or hardpan, which will stand without support while the bell is being excavated. The side slopes of the enlarged section usually make an angle of about 60 deg. with the horizontal. The sides are again made vertical for a distance of about 6 in. at the bottom. The bell should be designed as a spread footing, with reinforcing near the bottom to carry tensile stresses if they exceed allowable values for plain concrete footings, but this is not necessary unless the slopes are flatter than 60 deg. Hollow piers, as shown in Fig. 15*f*, carried deep into soil are often used to support bridges where the size of the upper portion of a pier is controlled by the dimensions of the bridge and not by the load to be carried. Such piers are not used for buildings.

Various methods are used in excavating for piers. In all these methods, some device, such as sheathing, sheet piles, or caissons, is used to hold back the earth and to keep out water. In one method, mud-ladened water which stands in the excavation prevents caving until some form of casing is provided. The sheathing or sheet piles may be removed as the concrete is placed in the well, but ordinarily they are left in place. Caissons are always left in place and become a part of the piers. At one time brick and stone were used in the construction of the piers, but now concrete is used exclusively. Timber and steel which are used during the process of excavating and which are left in place will not rot or rust excessively if they are below the ground-water level.[31,33]

The eccentric effect of wall columns adjacent to the property line is taken care of by reinforced-concrete or steel cantilever girders extending from the wall piers to the nearest interior columns, as shown in Fig. 41. The joint use of piers by two adjacent buildings is often arranged to avoid the expensive cantilever construction for wall-column foundations.

The methods used for excavating wells for concrete piers may be divided into two general classes, with several subdivisions under each class as follows:

Open-well methods:

- **Simple excavation.**
- **Vertical sheathing.**
- **Poling boards.**
- **Horizontal sheathing.**
- **Sheet piling.**
- **Steel cylinders.**
- **Boring.**

Caisson methods:
- **Box caisson (not used on buildings).**
- **Open caisson.**
- Pneumatic caisson.

In the open-well methods, the excavation is carried on under atmospheric conditions, the earth and ground water being held back in various ways. Caissons are used only where ground water is present in large amounts. The earth is held back by the caisson, but the excavation is carried on through the water or the water is held back by a plug of earth in the bottom of the caisson, so that open-air methods can be used, or the water is held back by compressed air while the excavation is carried on by men working in the compressed air. Box caissons are not used where excavation is required and are not used for buildings.

The open-well methods can be classified as *cofferdams* if ground water is present. In general, a cofferdam may be defined as a temporary structure built to exclude water from a given area so that work may be carried on in that area under atmospheric conditions or *in the dry.* Some leakage is to be expected, but this is controlled by pumping.

The method adopted in any excavation depends upon the nature of the soil, the depth of the excavation, the type of foundation under adjacent buildings, and upon many other factors. The simplest material, so far as excavation is concerned, is firm clay. This soil is usually sufficiently water-tight so that excavation in clay can be carried far below the ground-water level by open-air methods of excavation, any leakage of water that develops being taken care of by pumps. Water-bearing seams of sand and gravel introduce complications which may make it necessary to use a different procedure than would normally have been followed, but it may be possible to seal off these seams in some manner. Firm clay is a simple material to excavate for another reason, i.e., it will stand unsupported without caving while excavation is being carried on for several feet of depth and will give ample time to provide support. In some cases, wells excavated in clay for caissons over 100 ft. deep have stood unsupported for several hours.[50, 58]

Hardpan usually introduces no difficulties in excavation. It is reasonably water-tight and will usually stand unsupported until the concrete for the pier is being poured.

Saturated sand offers little resistance to the penetration of caissons, but it requires that special methods be used in order to keep soil which surrounds an excavation from flowing into the excavation. Soil excavated that is in excess of the volume occupied by the pier may have come from under adjacent foundations and have caused them to settle. This is called *lost ground.* Every effort is made in constructing founda-

tions for buildings to avoid lost ground. This may not be serious where bridge piers are being excavated and if the piers are located in areas that are not built up, as is commonly true.

Boulders are often present on rock strata which are to be used to support piers. By some methods boulders are difficult to remove and interfere with the advancing of the caisson and the establishing of the necessary seal between a caisson and the rock.

Most of the time, piers founded on rock rest on the rock surface or are carried only a short distance into the rock to secure sound bearing. Very little excavation, therefore, is required in rock.

Two or more of these methods are frequently combined in a single well where different types of soil are encountered as the excavation progresses.

The various methods used in excavating for piers will now be described.

Simple Excavation. Wells or pits may often be excavated in stiff clay with no support whatever to prevent caving and with no provision for keeping out water. The excavation is carried on with pick and shovel in the usual manner or with air spades, as described later, and the excavated material is removed in buckets hoisted by hand or power.

Vertical Sheathing. In excavating wells or pits for concrete piers the earth sides may be held in place by sheathing. This sheathing may be of wood planks placed vertically and supported by wood frames consisting of longitudinal members called *wales* or *rangers* and of transverse members called *braces*, as shown in Fig. 42*a*. The sheathing is driven down as the excavating proceeds. It is not practicable to drive sheathing that is more than 10 to 16 ft. long; so for excavations deeper than this it is necessary to drive a second set of sheathing a few inches inside the first, and so on, until the required depth is reached, as shown in Fig. 42*b*. This method is not used to any extent at the present time for excavating wells, principally on account of the decreasing area of the section as the depth increases.

The decreasing section provided by the method described in the last paragraph may be avoided by sloping the sheathing outward sufficiently to permit the driving of the next set without decreasing the section. This method is illustrated in Fig. 42*c*. The outward inclination of the sheathing creates an objectionable condition at the corners which makes this method unsatisfactory in material such as loose sand, for it is difficult to keep this material from running through at the corners.

Poling-Board Method. In material such as clay, which will stand well, vertical sheathing may be placed in short lengths of 4 or 5 ft. as

the excavation proceeds, as shown in Fig. 42*d*, instead of driving the sheathing, as described in the previous paragraphs. Wells excavated in this manner are usually circular. In starting a well, the first 4 or 5

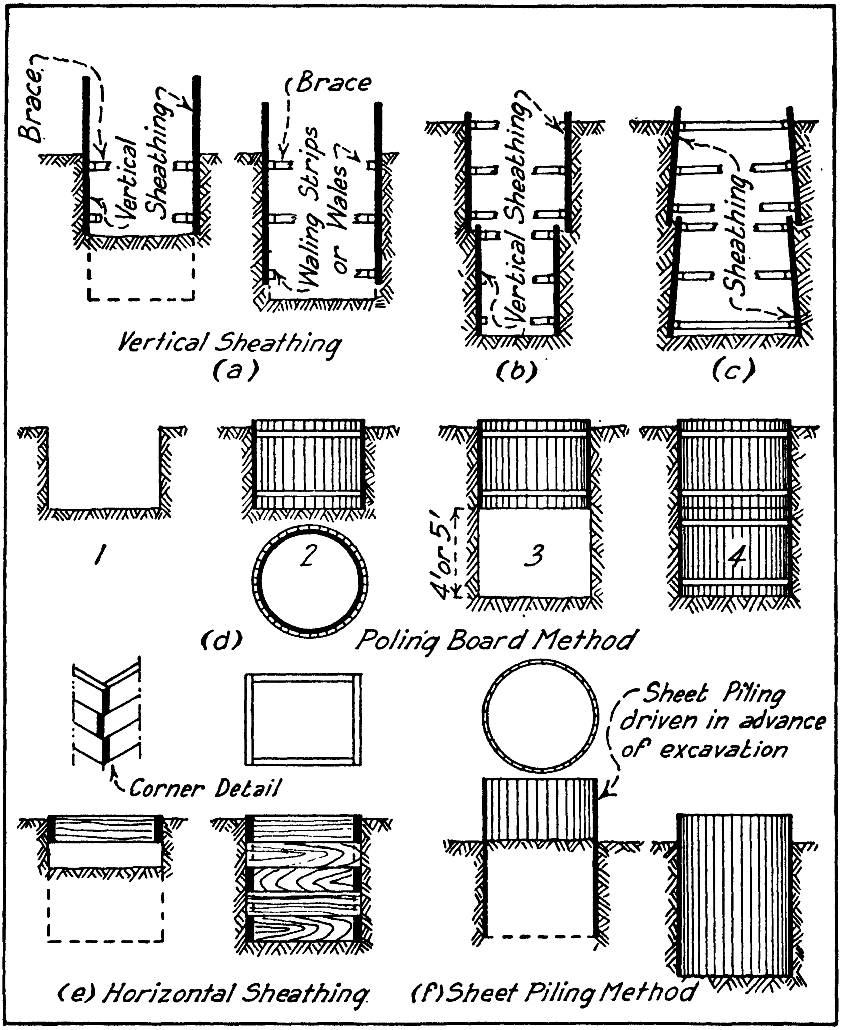


FIG. 42. Horizontal and Vertical Sheathing and Sheet Piling for Open Wells

ft. of depth is excavated and a set of sheathing is placed, the boards being held in place by metal rings placed inside, forcing the sheathing against the earth which must be accurately excavated if good results are to be secured. After the first set is in place, another 4- or 5-ft.

section is excavated, another set of sheathing is placed, and this process is repeated until the desired depth is reached. If difficult material is encountered, the sections may be as short as 18 in. or 2 ft. The earth is excavated by pick and shovel, or the pneumatic spade may be used. The pneumatic spade operates on the same principle as the air drill, but the drill is replaced with a spade. As the handle of the spade is pushed, the spade is driven into the earth by compressed air. The earth is hoisted to the surface in buckets by hand or power. A tripod supporting a sheave wheel is placed over the well for convenience in hoisting.

The sheathing is 2-in. or 3-in. tongue-and-groove lumber beveled to fit the curve, and the rings vary in size from 3 in. by $\frac{3}{4}$ in. to 4 in. by 1 in. The rings are divided into semicircles with flanges at the ends so that they may be bolted together in pairs to form the complete circle. In the wells for the Cleveland Union Terminal Building, some of the clay squeezed into the excavation threatened to collapse the lining. This was prevented by inserting, where necessary, heavy wooden drums divided into two segments which were forced against the lining by jack screws. These drums were removed as the wells were filled with concrete. See Fig. 52.

When using this method for excavations carried below the ground-water level some pumping will usually be necessary, for water will enter through seams in the otherwise impervious clay. It is necessary to supply fresh air to the men who are working in the wells. If pneumatic spades are being used the exhaust may be sufficient for this purpose, but frequently poisonous and explosive gases are encountered and it becomes necessary to supply a large amount of air by blowers which force the air through air lines extending to the bottom of the wells. See Fig. 52.

This method is commonly called the *Chicago method*, for it is extensively used in Chicago. The sheathing placed by this method is often called a caisson, but it is really a cofferdam.

The deepest foundations which have yet been placed were constructed by this method. Sixteen piers for the Cleveland Union Terminal Building were carried to a depth of 262 ft. below the curb and nearly 200 ft. below the ground-water level. A combination of horizontal sheathing, steel-sheet piles, and poling boards was used, as shown in Fig. 52.

Horizontal Sheathing. Planks to retain earth may be placed horizontally, as shown in Fig. 42*e* and Fig. 52, the wells excavated in this manner being square or rectangular in section. In this case the excavation need only be carried a few inches below the last set of sheathing

to provide room for the next set; thus the method is applicable to soils which would not stand if a considerable depth were exposed. The sheathing usually consists of 2 by 8-in. or 2 by 10-in. planks called *curb planks,* placed on edge, but in difficult material the width may be 6 in. or even 4 in. The earth is excavated with pick and shovel or with pneumatic shovels and is hoisted in buckets operated by hand or power.

Sheet Piling. Instead of supporting the earth with sheathing, as in the methods just described, sheet piling may be driven around the perimeter of a well in advance of the excavation, as shown in Fig. 42*f*. The

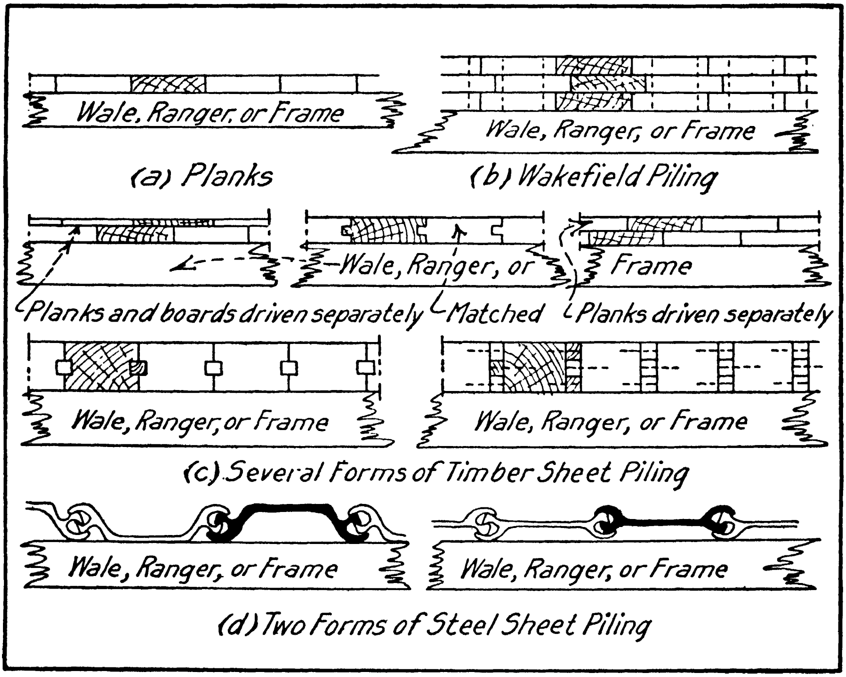


FIG. 43. Types of Sheet Piling

enclosed earth is commonly removed by pick and shovel or by pneumatic shovels and is hoisted in buckets. If driving is easy, the sheet piling may be driven its entire length before the excavation is commenced, but in all cases the piles are kept well in advance of the excavation. The piles are braced by horizontal frames placed as soon as the progress of the excavation will permit.

Sheet piling may be made of wood, steel, or reinforced concrete. Reinforced concrete is not used in constructing wells for piers. The simplest form of wood-sheet piling consists of wood planks driven side

by side, as shown in Fig. 43*a*. This type will hold back earth but will not keep out water. The most common form of wood-sheet piling is the Wakefield piling, illustrated in Fig. 43*b*, consisting of three planks spiked together to form a tongue and groove. Other forms of wood-sheet piling are shown in Fig. 43*c*. With the exception of the simple planks, all the forms are intended to keep out water as well as to hold back earth. Various forms of steel piling are shown in Fig. 43*d*. If wood piling is used, the well should preferably be square or rectangular in section, as shown in Fig. 44*a*, but, if steel piling is used, a circular section gives good results.

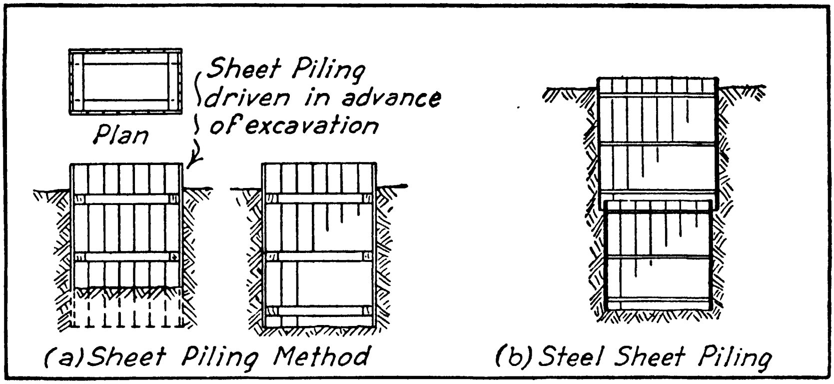


FIG. 44. Use of Sheet Piling

Wakefield piling will stand the impact of drop hammers but steel-sheet piling is usually driven with steam or air hammers. Wood-sheet piling is sometimes driven with heavy wood mauls.

For wells over 20 or 25 ft. deep it may be desirable to employ two or more sections of piles, offset as shown in Fig. 44*b*, the second section being driven a few inches inside the first section after the excavation has been completed to a point near the bottom of the first section, and so on for other sections, allowing sufficient overlap to provide a seal in each case.

This method has been used for wells up to 60 ft. in depth and, if some form of water-tight piling is used, it is applicable for use in digging wells below the ground-water level if the amount of water which enters the excavation is not too great to be removed by pumping or not great enough to wash an excessive amount of the material surrounding the piling under the piling into the well. Frequently the piles are driven through porous water-bearing material until the ends of the piles are

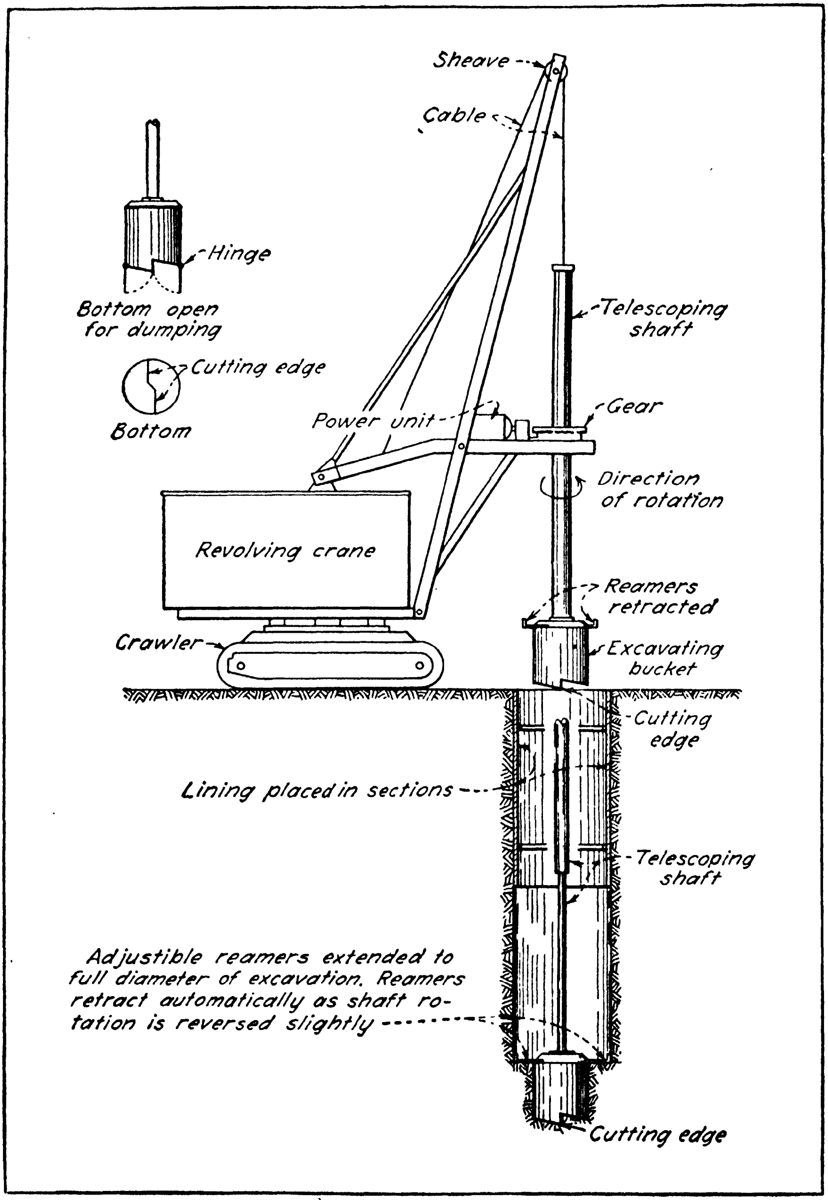


FIG. 45. Well Bored in Clay

embedded in clay. The clay effectively seals the bottom of the excavation so that water can not enter.

Bored Wells. Wells for piers 7 ft. in diameter have been successfully bored in firm, impervious clay to depths of 120 ft. A short, steel-cylinder excavating bucket is mounted at the lower end of a telescoping vertical shaft, as illustrated in Fig. 45. The shaft is supported on a crawler-mounted, full-revolving, electric-powered crane. The bottom of the bucket consists of two semicircular hinged gates set at opposite slopes and provided with cutting edges so that they form an augur which cuts into the soil on the bottom of the excavation as the shaft rotates and forces the soil into the bucket. The gates are hinged at their outside edges so that the bucket operates as a bottom-dump bucket. The vertical shaft and the bucket are raised when the bucket is filled. The supporting equipment is so arranged that the bucket can be moved sideways and dumped into a truck. Adjustable reaming knives are attached to the bucket so that holes of various diameters can be cut, using the same bucket. Wood lagging or other casing is placed in the holes as the drilling progresses or after a hole is completed. The time required to excavate a well 100 ft. deep may be as short as one day. This method has been used successfully in dry and predrained soils, as well as in the firm clay mentioned above. This equipment was developed by the Gow Company.[50,58]

Telescoping Steel Cylinders. Telescoping steel cylinders from 5 to 8 ft. in length may be used in place of vertical sheathing or sheet piling. These cylinders differ in size by 2-in. increments. The largest cylinder is sunk first, as shown in *1*, Fig. 46*a*, by excavating below the cutting edge and driving the cylinder down. The excavation is carried on by hand methods. After the first cylinder is in position, the second is sunk in the same manner and others in succession until the desired depth is reached, as shown in *2*, Fig. 46*a*. A bell, as shown in *2*, is excavated at the bottom if the soil permits. After the excavation is completed, the space is filled with concrete, as shown in *3*, the cylinders being withdrawn as the concrete is placed until the completed pier, as shown in *4*, is formed. The waste of concrete due to the decreasing section may be avoided by using a small-sized cylinder as a concrete form for the entire depth, the space between the concrete and the outer lining being filled with sand. Telescoping cylinders can be used in water-bearing soils where the material will not hold its shape as required by the poling-board method, the cylinders being driven well in advance of the excavating to keep the surrounding soil from flowing into the excavation. A bell can not be formed unless the final excavation is in a suitable material such as clay. This is one form of the Gow pile and might be classed as an open caisson.

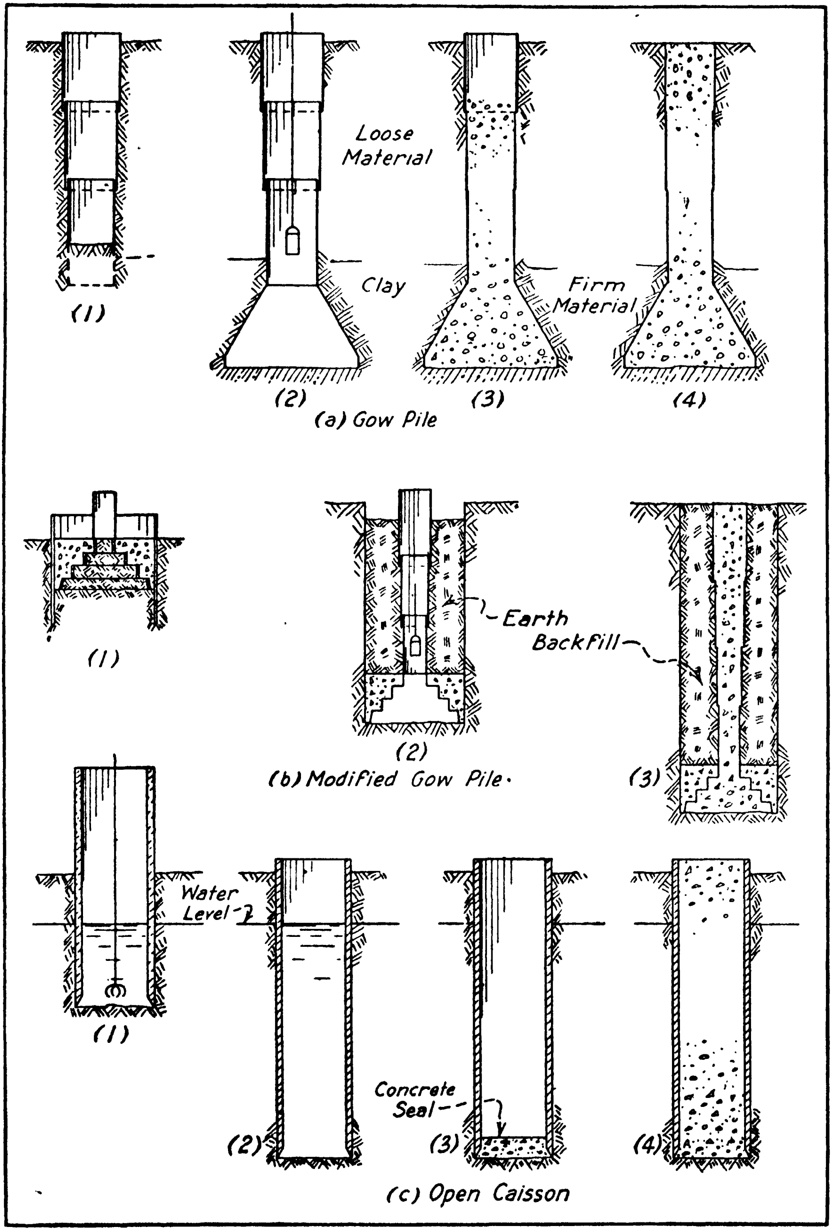


FIG. 46. The Gow Pile and the Open Caisson

Another form of the Gow pile has been devised for use when the enlarged base is desired and the soil will not permit the base to be belled out, as in the type just described. In this type, a working chamber forming the enlarged base, as shown in *1*, Fig. 46*b*, is constructed of concrete in a properly shaped excavation. The earth in the working chamber is excavated by hand and, as the excavation proceeds, the working chamber sinks.

A shaft consisting of telescoping steel cylinders, as in the other form of Gow pile, is used to provide a passage from the working chamber to the surface. The earth which is excavated is used for backfilling between the shaft and the surface, over which the sides of the working chamber moved, as shown in *2*. This earth rests on the top of the working chamber and provides the weight which forces it down as the excavation proceeds.

When a suitable foundation bed is reached, the working chamber and shaft are filled with concrete, as in *3*. This forms a pier with an enlarged base for use on soils with a bearing power relatively low as compared with the strength of concrete. If a pier is to rest on bed rock, of which the bearing power is at least equal to the strength of the concrete in the pier, an enlarged base is not necessary and this method of construction is not suitable. Under these conditions the ordinary form of Gow pile, omitting the bell, can be used if water is not encountered in serious quantities, or some other method such as the poling-board method may be suitable. If water is present in large quantities, the open caisson or the pneumatic caisson will have to be used. A form of the Gow pile for use in water-bearing soils which require the pneumatic process is described under Pneumatic Caissons. All forms of the Gow pile are patented.

Types of Caissons. The term caisson is derived from the French word, *caisse*, meaning box. There are three forms of caissons used in constructing foundations under water, i.e., the box caisson, the open caisson, and the pneumatic caisson.

According to Jacoby and Davis:[51]

> . . . a caisson is a box; if open at the top and closed at the bottom it is a *box caisson*; if open both at the top and bottom it is an *open caisson*; while if it is open at the bottom and closed at the top and utilizes compressed air, it is a *pneumatic caisson.*

It is sometimes difficult to distinguish between a cofferdam and a caisson. In general, if the structure is self-contained and does not depend upon the surrounding material for support, it is a *caisson*; but, if it requires such support, as in the case of sheathing, poling boards, and sheet piling, it is a *cofferdam.*

Box Caissons. Box caissons are used in constructing bridge foundations under water where little excavation is required except for preparing the site to give good bearing for the caisson. The caisson, which may be constructed of timber, reinforced concrete, or steel, is towed into posi-

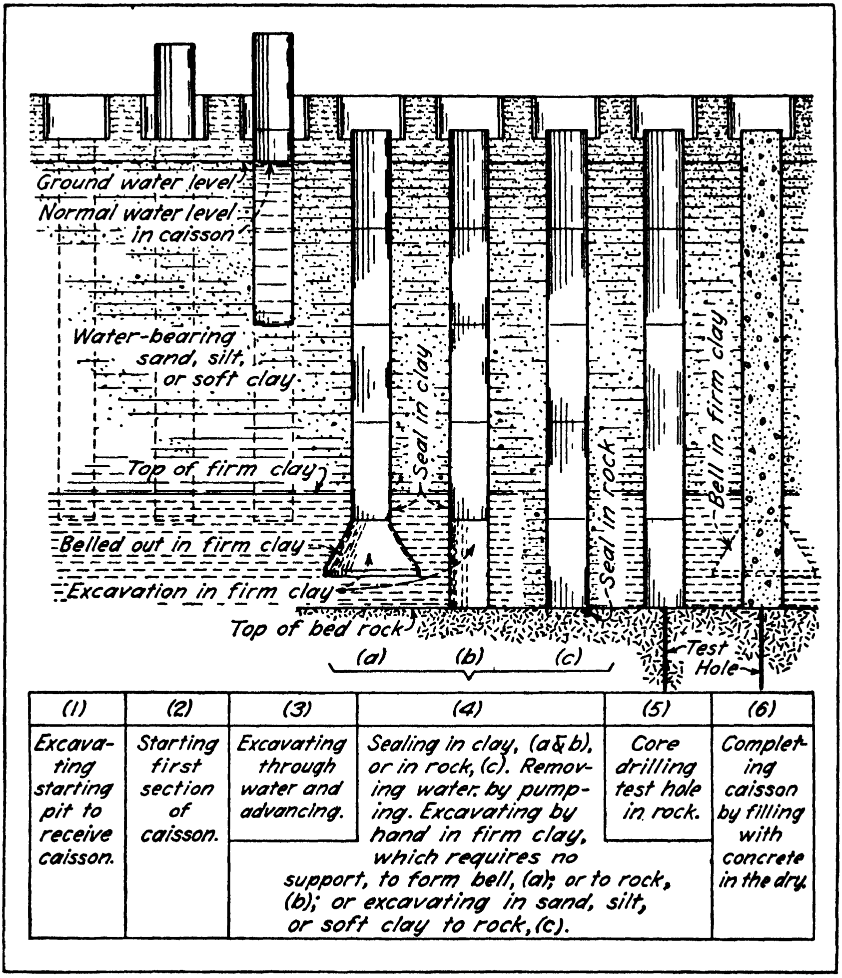


FIG. 47. The Open-Caisson Method

tion; filled with concrete or stone masonry and sunk until it rests on the river bottom which has been prepared to receive it, or on a pile cluster, to form the lower part of a bridge pier. Box caissons are not applicable to foundations for buildings.

Open Caissons. The open-caisson method consists of the following operations, as shown in Fig. 47.

1. *Constructing* the caisson and preparing site of pier to receive it.
2. *Placing* the caisson over the site of the pier.
3. *Excavating* the soil on the interior of the caisson and *advancing* the caisson so that its cutting edge is at or below the bottom of the excavation and continuing this process until the foundation stratum is reached.
4. *Sealing* the bottom of the caisson to exclude water and soil.
5. *Preparing* the excavated space to receive concrete and *examining* the foundation bed.
6. *Placing* the concrete to form the pier.

Each of these operations is explained in the following paragraphs.

The caissons are usually cylindrical in form, from 2 ft. to 8 ft. or more in diameter, and are made of steel plates riveted or welded together or are made of reinforced concrete. The thickness of the steel plates depends upon the size of the caisson, upon the material to be penetrated, upon the method of advancing, and upon other factors. The thickness varies from $\frac{1}{4}$ in., or even less, to a maximum of about $\frac{3}{4}$ in. The cutting edges are often reinforced with steel bands placed on the inside. A steel caisson may be a single unit for the entire length, or its length may be increased by adding sections as the sinking progresses. The length of a reinforced-concrete caisson is normally increased by pouring new sections, in lifts, as the sinking progresses.

A caisson is usually started in a sheeted *starting pit* above the ground-water level. To maintain the caisson in a vertical position it can be propped against the side of the pit, but it is often necessary to erect towers for this purpose.

The method used in excavating a caisson depends upon the method used in advancing it into the ground; therefore these two phases of the operation must be considered together. However, the various methods for performing each operation will be listed separately. The methods for removing the soil from the interior of the caisson are:

a By hand methods using the pick and shovel or the pneumatic spade to loosen and to place the soil in buckets in which it is hoisted to the surface. Such methods are, of course, suitable for use above the ground-water level and for use below the ground-water level only when the water which flows under the cutting edge and into the caisson can be controlled by pumping. See Fig. 48*b*.

b By orange-peel and small clam-shell buckets which can be operated through water, as shown in Fig. 48*a*. These are often called *grab buckets* because they "grab" the soil and fill themselves.

c By interior water jets which loosen the soil and raise the water level inside the caisson above that outside and thereby cause soil-ladened water to flow outward under the cutting edge of the caisson and upward along the outside of the caisson to the surface, as shown in Fig. 48*c*. Trenches are provided to receive the water and to conduct it to the sump of the pump supplying the jets. The coarser soil deposits in the trenches and is shoveled into trucks, and the finer soil is recircu-

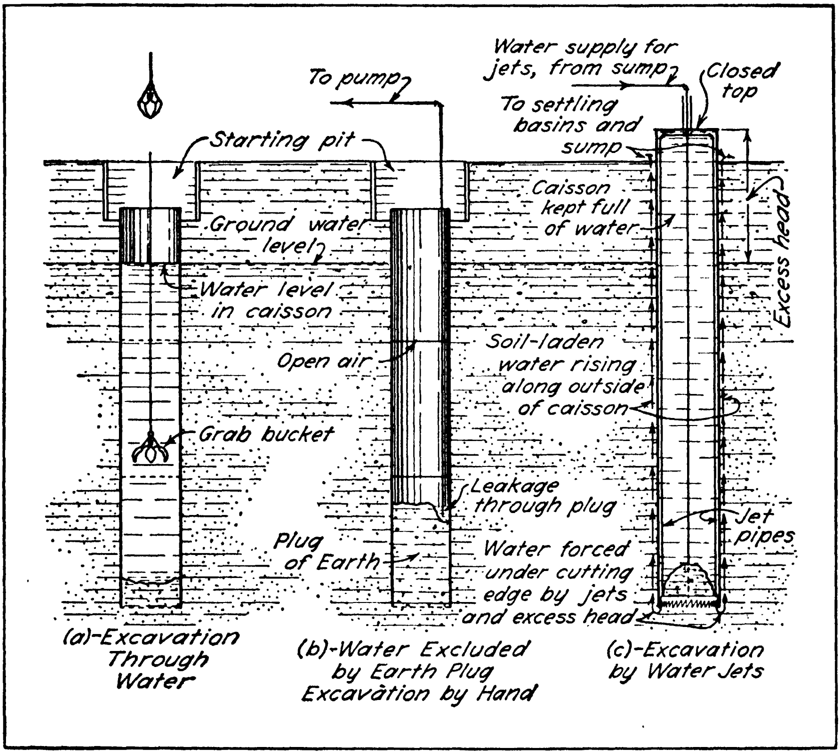


FIG. 48. Methods for Excavating in Open-Caisson Method

lated through jets.[52] This method of excavation is used only with the rotary caisson listed below as *g* in the following methods for advancing caissons.

Methods of advancing the caisson into the soil are:

a By the weight of the caisson itself. This is always a factor in advancing the caisson; and, in some soils, reinforced-concrete caissons may have sufficient weight so that no other force need be applied.

b By loads applied to the top of the caisson. These may be large concrete blocks, steel rails, etc.[51,53]

c By driving the caisson with pile hammers. This procedure is applicable only to steel tubular caissons reinforced at the top and thick enough to stand driving. One hammer, acting on a beam across the top of the caisson, may be sufficient; or two hammers, acting simultaneously but not necessarily synchronized, may be required.[54]

d By reducing the resistance to penetration with water jets around the cutting edge to loosen and displace the soil.[51,52,59] Water jets supplement the weight of the caissons and are often used with loaded caissons or caissons driven with hammers.

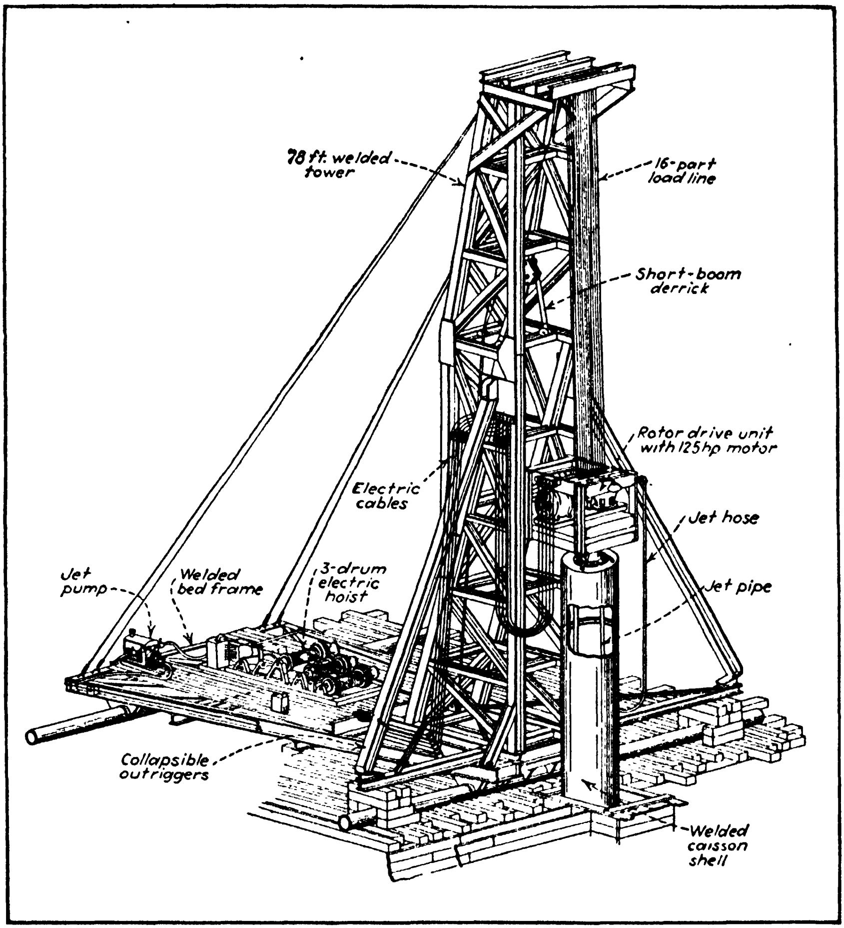
e By reducing the resistance to penetration by drilling and blasting below the cutting edge to break up material which is difficult to penetrate,[54] and by blasting near the cutting edge to jar the caisson loose momentarily and permit it to fall a short distance.[53] These procedures are occasionally used to supplement other methods for advancing a caisson.

f By driving the caisson with hydraulic jacks. This is possible only when there is a load to jack against, as there usually is in underpinning.

g By using the caisson itself as a drill and by rotating it so that it cuts into the ground, as shown in Fig. 49. This is, of course, possible only with steel cylindrical caissons. Large teeth may be cut in the bottom edge of the cylinder. These are bent somewhat, alternately in and out or "set," as with a wood saw. The teeth are hardened to resist wear. The cylinder is capped with a head plate, to which the vertical shaft which rotates the cylinder is attached. Power may be supplied by an electric motor. Good results have been secured by setting the axis of the shaft slightly off center in relation to the caisson axis so that the caisson wabbles a little and thereby forms a hole slightly larger than its outside diameter. Water jets are used to soften the soil under the cutting edge and to remove soil from the cutting edge and from the interior of the caisson, as described above.

The common procedure, which is illustrated in Fig. 46*c*, consists of advancing the caisson by placing loads on its top and by excavating by hand until the ground-water level is reached. Below this level, water will usually enter the caisson under the cutting edge at such a rate that it can not be controlled satisfactorily by pumping unless large quantities of soil are carried into the caisson. Excavation is, therefore, continued by means of an orange-peel or clam-shell bucket. A serious objection to this procedure is the possibility of undermining adjacent footings by the *lost ground* which is brought into the caisson by the incoming water, even when excavating through water. If the soil being penetrated is fine sand, this action is quite pronounced, but

it may cause no difficulty in some clay soils. If the soil being penetrated is clay with seams of pervious water-bearing soil, it may be possible to use hand-excavation methods while the clay is being penetrated and to resort to grab buckets only while penetrating the pervious



Engineering News-Record, July 11, 1935

FIG. 49. Open-Caisson Method Using Rotating Caisson

seams.[58] Penetration may be facilitated by water jets if excavation is being made through water. In some soils, water jets may make the addition of loads to the top of the caisson unnecessary.[59]

If the caisson is being driven with pile hammers or being forced down with hydraulic jacks, the cutting edge may be driven far enough in advance of the excavation so that the plug of soil in the bottom of the cais-

son, as shown in Fig. 48*b*, reduces the flow of water until it can be readily handled by pumping and is so slow that there is little ground lost. Under these circumstances the soil can be removed by hand methods.

Good results have been secured in several instances by using the caisson itself as a drill, as previously described and as illustrated in Fig. 49. When this method is used, the top of the caisson is closed and no excavation can be carried on by this route. Most of the soil is removed under the cutting edge by the outward flow of the water supplied by the jets. The space outside the wall of the caisson, created by the wabble of the caisson, facilitates the upward flow of the soil-ladened water. The soil not removed by the water jets and also any stones or boulders encountered accumulate at the bottom of the caisson. These are removed after drilling has ceased and the head plate has been taken off. Any boulders encountered by the cutting edge are torn loose and deposited in the caisson or, if firmly embedded, are cut through by the cutting edge. Penetration is much more rapid by this method than by any other method already described.[52]

If the pier is to be founded on firm clay or hardpan, the caisson is carried down far enough into the material to form a seal, as shown in Fig. 47, *4*, and any water present is pumped out.[59] Bells for the enlarged pier bases are formed by excavating in the dry, using hand methods. If clay or hardpan lie immediately above rock which is to be used as a foundation bed, the seal is established, as shown in Fig. 47, *4*, and excavation is carried on through these materials to rock, using the above procedures, the clay walls being supported by poling boards or by whatever is necessary. No support would usually be required in hardpan, and often none is required for clay.[56]

If the porous water-bearing soil continues until rock is reached, the caisson is carried to the rock and a seal must be established between the bottom of the caisson and the rock. Where the excavation has been carried on through a water-filled caisson, as shown in Fig. 46*c*, the rock is cleaned off as well as possible with the grab bucket or with other devices, possibly with the aid of a diver who makes all possible preparation and examination of the foundation bed. A concrete seal is then placed in the bottom of the caisson, using a bottom-dump bucket. After this seal has set, the caisson is pumped out and is ready for concreting.

When the caisson has been driven or forced down with a hydraulic jack, an effort is made to drive the bottom of the caisson far enough into the rock to form a seal. If a plug of soil has been maintained in the bottom of the caisson to retard the flow of water enough to permit

the use of hand-excavation methods, this plug can not be removed until the seal is established. Cement grout, pumped around the cutting edge, may be of assistance in this operation. If the caisson is used as a drill, a channel is drilled into the rock by the cutting edge, if possible, and this effectively seals the bottom. An uneven or sloping rock surface adds greatly to the difficulty of making the seal.

If the various methods, described above, for making a seal between the bottom of a caisson and the rock are unsuccessful or, if a seal placed through water is considered unsatisfactory because of the lack of opportunity for preparing and examining the foundation bed, the open caisson can be converted into a pneumatic caisson by placing a top on the caisson and attaching air locks. Any water present is removed and the work of preparing and investigating the foundation bed and of sealing the joint between the caisson and the rock is carried on under compressed air, as described under Pneumatic Caissons. It may be necessary to resort to this procedure before rock has been reached if boulders or other obstructions are encountered which can not be passed in any simpler way. Layers of boulders are often found on top of bed rock.

Some of the procedures which have been described, particularly those associated with the use of the caisson as a drill, have been patented. Men who have been associated with the development of this method are Charles L. Powell and J. A. Montee.

In general, the open-caisson method is cheaper than the pneumatic-caisson method and is not subject to a depth limitation, as is the pneumatic-caisson method. The disadvantages include the possibility of lost ground, which usually must be guarded against, and the lack of opportunity for preparing and examining the foundation bed where the pier is to be founded on rock and the seal is placed through water. The various modifications of the basic method attempt, more or less successfully, to overcome these objections and to decrease the time required.

Concrete Piers with Structural-Steel Core. The capacity of concrete piers in steel-plate caissons and concrete-pipe piles can be increased by inserting a structural-steel H section, as shown in Fig. 50, which illustrates one of the piers for the Department of Sanitation Building in New York City.[37] Because of the introduction of the steel core, the bearing capacity at the surface of the rock stratum was insufficient to carry the load transmitted by the pier. The required additional capacity was secured by drilling into the rock a hole whose diameter was equal to that of the outside of the shell. The H section was carried several feet below the surface of the stratum. The shell and the hole in the rock were then filled with concrete, as shown in the figure.

By this means, the pier load was distributed over a much greater area at the elevation of the bottom of the pier than it would have been if the pier had been supported on the surface of the rock. The assumed distribution of the stress in the rock is shown on the figure. This was determined by the allowable bond strength between the pier and the surrounding rock and by the assumed direction of the lines of stress.

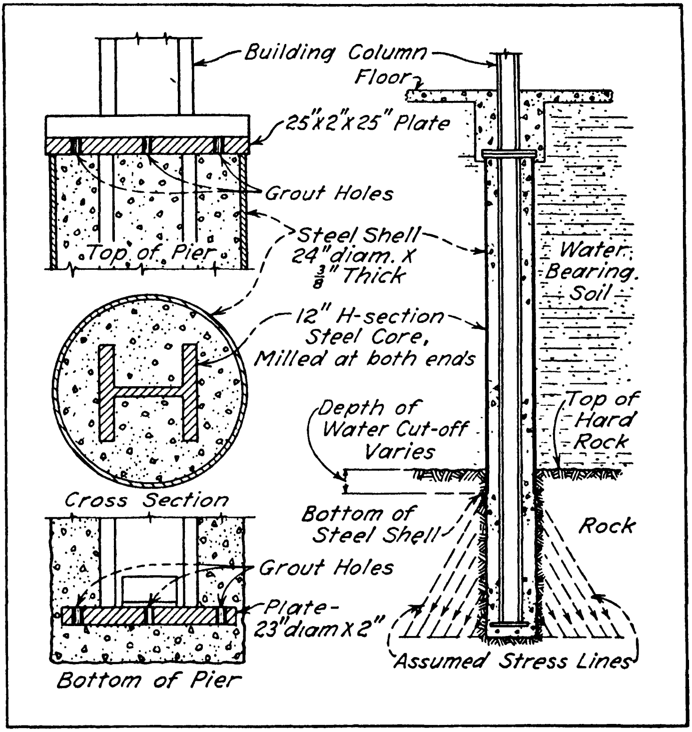
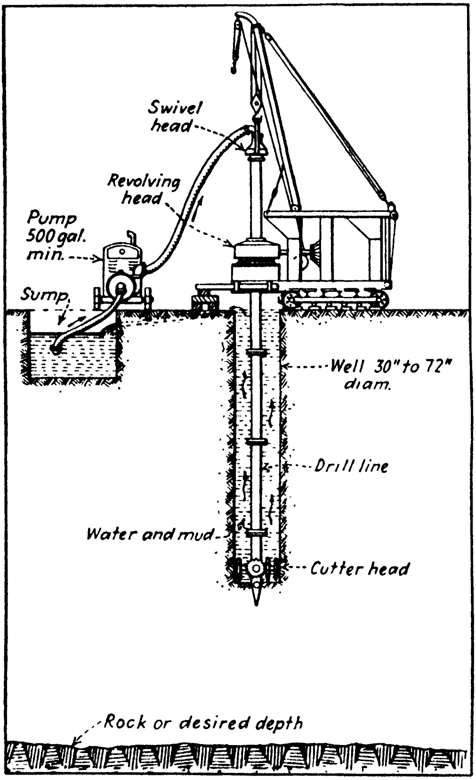


FIG. 50. Concrete Pier with Structural-Steel Core

In constructing this pier, the steel-caisson shell was driven to rock, the excavation being made through water. The hole in the rock was drilled through water to a sufficient depth to form a water-tight seal after the caisson has been driven down that distance into the rock. The caisson was then pumped out and the remainder of the rock excavation carried on in open air.

Wet-Process Caisson. In this process, a hole is drilled into the ground with a spud drill the size of the caisson diameter, as illustrated in Fig. 51. Water under pressure is forced down through the drill stem. It fills the excavation and overflows into trenches to a sump. The

loosened soil particles are picked up by the water. The coarser solids settle down in the sump, but the finer particles stay in suspension. This thick muddy water is circulated continuously down through the drill stem and back through the excavation, the trenches, and the sump. The pressure of the muddy water, with which the excavation is filled, keeps the banks from caving. If porous soil is being excavated, the loss of water into the soil is prevented by throwing clay into the excavation. As the drill is rotated, this clay coats the walls of the excavation and seals them. When the excavation reaches the bearing stratum, the drill is removed and a steel cylinder, whose diameter equals that of the pier, is lowered into the excavation and driven into the bottom material to form a seal. The muddy water in the excavation and the solids which have settled to the bottom are then pumped out or removed by a clam-shell or orange-peel bucket, the bottom is cleaned and concrete is deposited "in the dry" to form the pier. The spud drill consists of a heavy drill stem, which is held securely in a vertical position. To the bottom of the drill are fastened radiating arms mounted with scarifying teeth. These teeth are in contact with the bottom of the excavation and loosen the earth as the drill is rotated.



Construction Methods, November, 1932

FIG. 51. Wet-Process Caisson

Under certain conditions, the steel casing is removed, immediately after the concrete is placed, and is used again. If a satisfactory bottom seal can not be secured by the method just described, the spud drill is replaced with a shot drill, as described in Art. 14, and a ring from 6 in. to 1 ft. deep is drilled in the bearing stratum to receive the steel casing and to form the seal. In order to be economical, some means

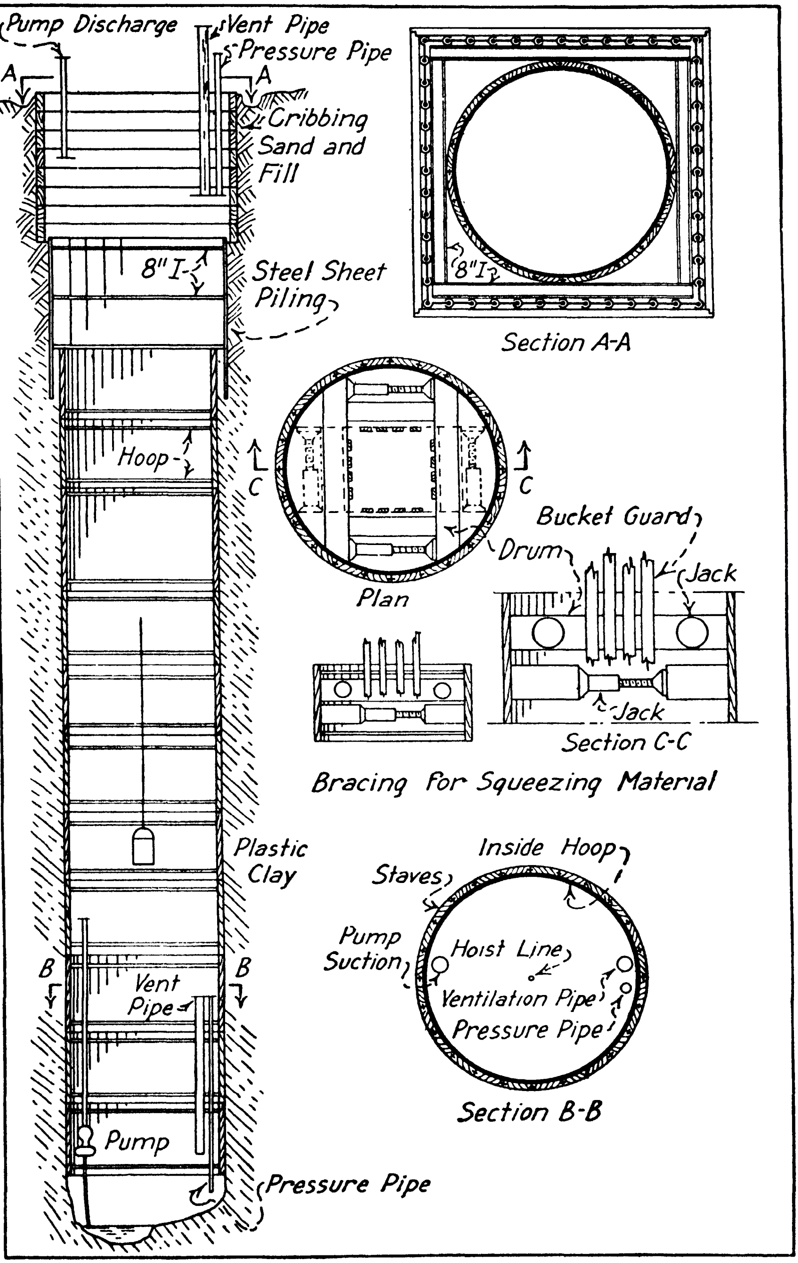


FIG. 52. Horizontal Sheathing, Steel-Sheet Piling, and Poling Boards in a Single Well

must be found for disposing of the wet excavated material inexpensively. The wet-process caisson is a relatively recent method and has not been used extensively.[58,60]

Combined Methods. It is frequently not feasible to use one method for the construction of the entire depth of a well, and two or more methods may be combined.

If a stratum of water-bearing material, such as water-bearing gravel or quicksand, lies on top of a thick stratum of clay which is underlain with hardpan or rock, sheet piling may be driven through the quicksand into the clay a sufficient distance to form a water-tight seal. The remainder of the depth may then be excavated by the poling-board method.

At the site of the Cleveland Union Terminal Building this condition existed, but the ground-water level was a few feet below the level at which the excavation for the well was started. The upper part of the well down to the ground-water level made use of horizontal sheathing, as shown in Fig. 52. Below this, and extending to the surface of the clay, steel-sheet piles were used and the remaining distance was excavated by the poling-board method.

Another combination of methods is illustrated in Fig. 53*a*. It has been developed to meet the situation in which a stratum of water-bearing gravel and boulders lies on top of the rock stratum where a pier is to rest, above which is a thick layer of clay. The poling-board method is used in the clay. Before the water-bearing-gravel stratum is reached, the well is stepped out, as shown in the figure, to give sufficient room to drive steel-sheet piling through the gravel to rock. The bottom of the poling-board excavation is kept far enough above the top of the gravel stratum so that the remaining clay will act as a seal to exclude water from the excavation. The sheet piling is driven into the bottom of the poling-board excavation and extends to rock. The piles are so driven that they form a seal between their lower ends and the rock; the enclosed earth gravel and boulders are cleaned out; the foundation bed prepared to receive the pier; and the concrete pier is poured. If water-bearing strata are encountered between two layers of clay, they can be passed if sheet piling is used following this procedure, as shown in Fig. 53*b*, or they can be sealed off with steel cylinders whose inside diameter is large enough to clear the poling boards.

On account of their relatively low cost, open caissons may be used to penetrate a water-bearing stratum of sand, gravel, or silt; but they may be so arranged that locks may be placed on top of the dredging wells to convert them into pneumatic caissons. This procedure may be adopted as a precaution should material which the open caisson will not pene-

trate be encountered; or it may be considered desirable to secure the advantages of the pneumatic-caisson method in preparing the foundation bed and in filling the caisson with concrete.

Many other combinations might be cited to meet varying conditions, but those which have been mentioned will serve as general illustrations.

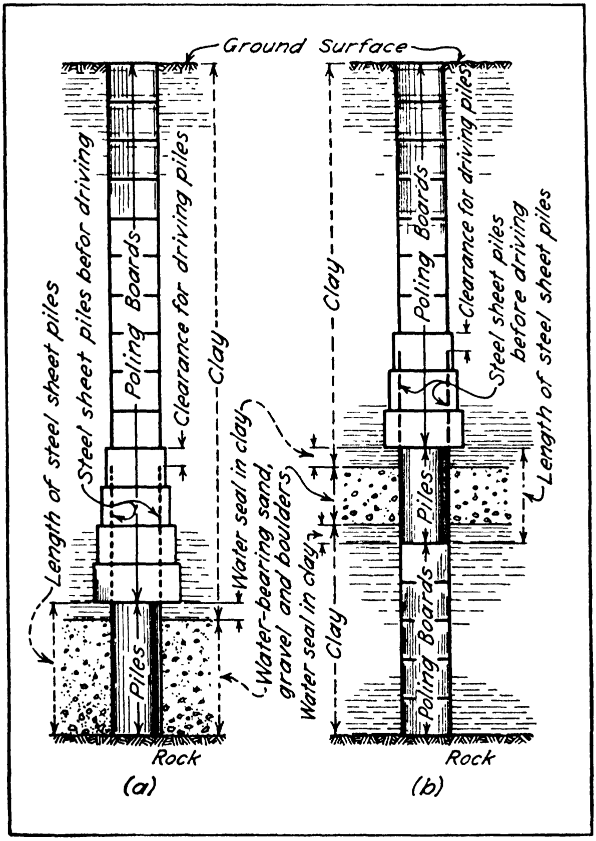


FIG. 53. Combined Poiling-Board and Sheet-Piling Methods

Pneumatic Caissons. Pneumatic caissons are extensively used for constructing building foundations which consist of piers carried through water-bearing material to bed rock. The essential parts of a pneumatic caisson are the working chamber, the shaft, and the air locks, as shown in Fig. 54*b*. The working chamber may be constructed of timber, steel, or reinforced concrete. The shaft is usually constructed of steel.

The pneumatic-caisson process is illustrated in Fig. 54*a*. The lower end of the caisson including the working chamber is first constructed and

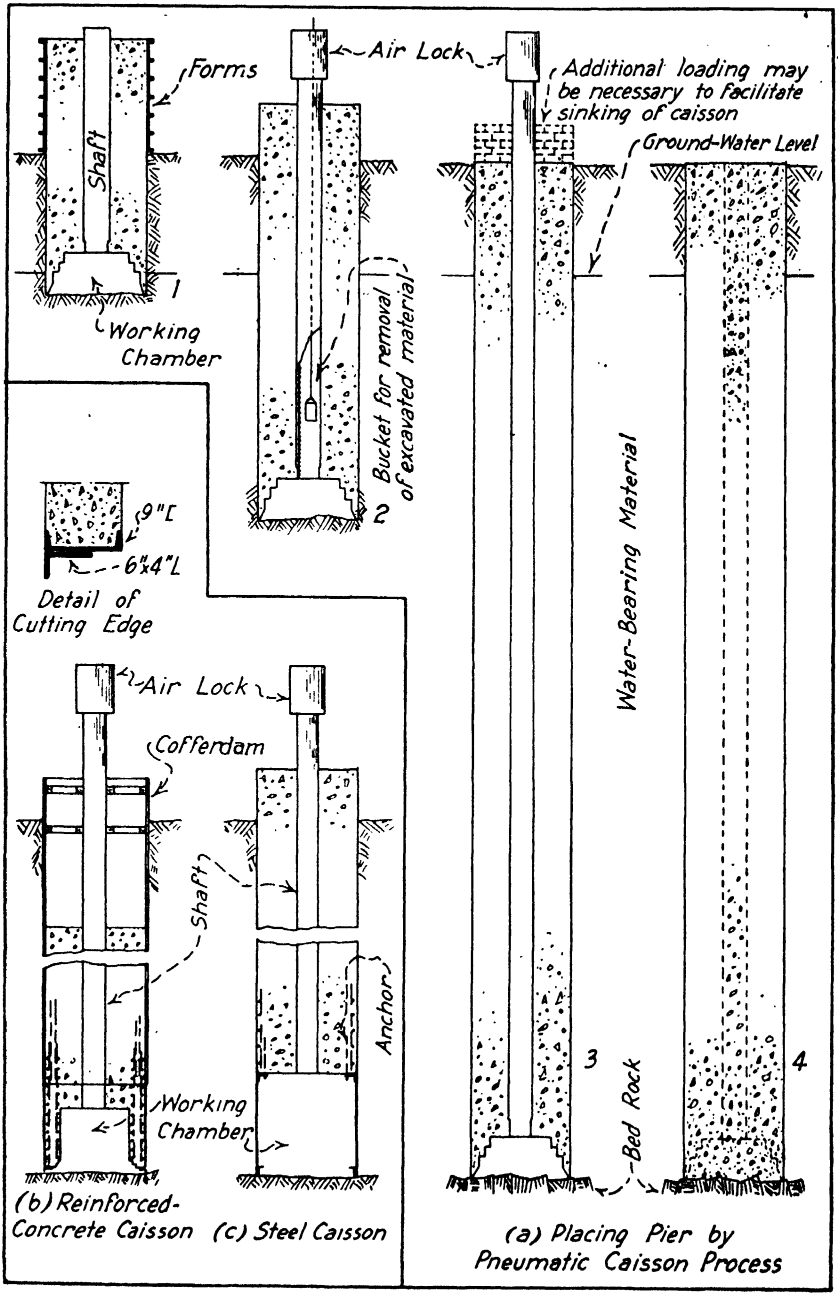


Fig. 54. Pneumatic-Caisson Method

placed on the surface of the ground or in a hole excavated to receive it, as shown in *1*. Excavation is carried on in the working chamber, and the caisson sinks either due to its own weight or because a necessary load was placed on it. As soon as the ground-water level is passed by the cutting edge, water begins to rise in the working chamber; therefore the air locks are placed at the upper end of the shaft as shown in *2* and sufficient air pressure is applied to the working chamber to force out the water. Men can now work in the working chamber without the interference of water. As the caisson sinks, the pressure in the working chamber must be increased to balance the water pressure.

The part of the caisson above the working chamber may be surrounded with a timber cofferdam, as shown in Fig. 54*b*, to hold back the earth and water as the caisson sinks. Concrete is placed in the cofferdam to form a part of the pier and to serve as a weight to assist in forcing the caisson down. Removable forms may be used instead of the cofferdams, as shown in Fig. 54*c*. The top of the concrete is always kept well above the top of the ground. The latter procedure provides more weight for forcing the caisson down, but the friction of the concrete against the earth is greater than the friction of the timber cofferdams and so more weight is necessary. Frequently the entire pier, as required by the depth from the surface to rock, is completed before the sinking starts.

The earth exposed in the working chamber is excavated by any convenient method, such as pick-and-shovel or air-spade, and is hoisted to the surface in buckets through the air locks. If the material is quite fluid it may be disposed of by blowing it to the surface through a pipe, the air in the working chamber providing the necessary pressure. Spoil which is to be blown out is heaped over the end of a stiff hose placed on the bottom of the working chamber and connected to the pipe leading to the surface. A valve is provided so that this pipe may be closed when not in operation.

When the cutting edge of the caisson has reached bed rock, as shown in *3* of Fig. 54*a*, the surface of the rock is prepared to support the pier. A layer of concrete thick enough to resist the hydrostatic pressure is placed in the bottom of the working chamber and allowed to set. This seals the caisson so that water can not enter. The air pressure is released, the air locks and possibly the shaft are removed, and concrete is carefully placed under atmospheric pressure in the remaining portion of the working chamber and the shaft, as shown in *4*. Care must be exercised to avoid air pockets and to overcome the effect of the shrinkage which occurs in the concrete while it is setting.

A form of the Gow pile has been devised for use where pneumatic methods are desirable. The working chamber is constructed, as in *1*, Fig. 46*b*, but an air-tight concrete shaft is used in place of the telescoping steel shaft which would not be air-tight. Air locks are placed on the shaft, compressed air is forced into the working chamber, and the process continues as in the usual type of pneumatic caissons. This type of pier is suitable for use when the foundation bed is a firm material such as hardpan, the bearing power of which is less than the strength of concrete, thus requiring the bearing area to be larger than the cross-section of the shaft. The enlarged base is not required if a pier rests on bed rock since the bearing strength of bed rock is usually much greater than the strength of concrete.

The advantages of the pneumatic process are as follows:

When properly operated, the only excavation required is that represented by the volume occupied by the pier; so adjacent foundations are not undermined as they may be with the open-caisson process. An opportunity is afforded to examine and prepare properly the foundation bed to receive the pier. This is not possible in the usual form of the open-caisson process.

The disadvantages are:

The limitation of the depth below the ground-water level to about 110 ft. because men can not work safely in the air pressure required by greater depths. (This depth requires a pressure of about 50 lb. per sq. in.) The cost, as compared with the open-caisson method, is high.

The pneumatic-caisson process is very extensively used in constructing the foundations for tall buildings, especially in New York City.

Caisson Cofferdams. Large buildings are often constructed with two or three floors below the ground level, and for some buildings as many as five underground floors have been provided. The excavation above the ground-water level is carried on by supporting the banks with vertical sheathing or piles in the usual manner. Where floors are located below the ground-water level it is necessary to provide watertight exterior walls.

The walls are commonly constructed by the pneumatic-caisson method and consist of a cofferdam of rectangular reinforced-concrete caissons from 5 to 8 ft. wide and 30 ft. or more in length, as shown in Fig. 55. Each caisson is preferably poured in one operation before sinking. In this way, horizontal joints are avoided and a more watertight caisson is secured. Each caisson is sunk until the cutting edge strikes bed rock. The space between the irregular surface and the cutting edge is filled in by underpinning with concrete to secure a watertight joint. The working chamber is then filled with concrete as de-

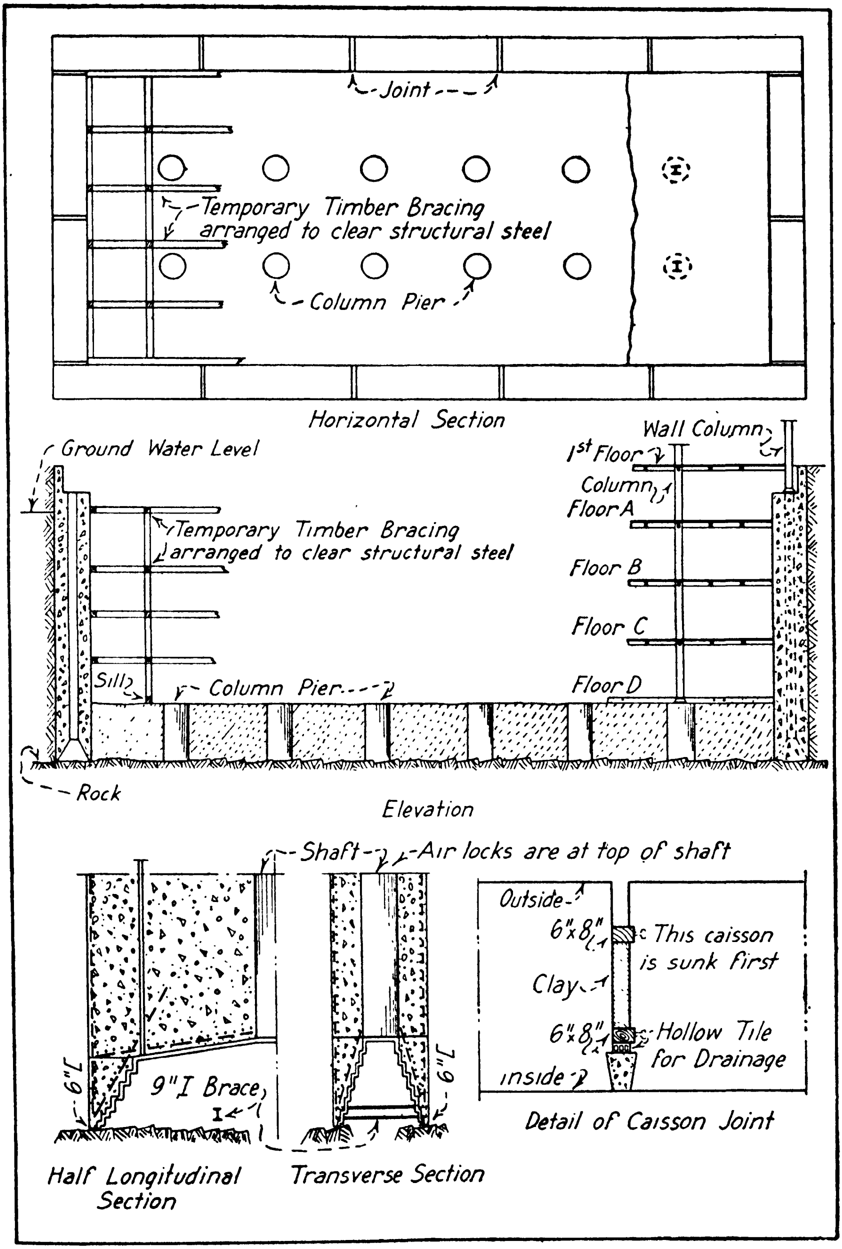


FIG. 55. Caisson Cofferdam

scribed under Pneumatic Caissons. The small pipe in the roof of the working chamber, shown in the figure, is a vent to permit air to escape and to avoid air pockets when the working chamber is filled, the seal having already been placed.

Many methods have been devised for making the joints between the caissons water-tight. One of the simplest methods was devised by T. Kennard Thompson,[61] and is shown in the figure.

The ends of adjacent caissons are kept 6 in. apart by two 6 by 8-in. oak timbers bolted vertically to the caisson which is sunk first. These timbers are 3 ft. apart. After the caissons are in place, a 4-in. pipe is jetted down to the cutting edge in the space between the timbers. The sand is washed out of this pipe, and slugs of clay are dropped down into the pipe. The clay is forced out of the bottom of the pipe by a ramrod struck lightly with the pile driver when necessary. The pipe is gradually raised as the joint becomes filled until the seal is completed to the top. If the clay is rammed too tightly the caissons may be forced apart. The remainder of the joint is placed after the excavation is completed, as will be explained later.

After all the caissons are in position and the clay seals are completed, the earth inside the cofferdam is removed to the desired depth. While this is being done it is usually necessary to provide temporary bracing to keep the caisson from being forced inward by the surrounding earth and water. This may be in the form of *cross-lot bracing,* consisting of timber struts extending both ways from wall to wall and supported vertically at the intersections, or horizontal trusses may be used to provide more clear working space. This bracing is placed as the excavation progresses and must be so arranged that it clears the structural frame which, when placed, takes the place of the temporary bracing. When possible, the floor construction is designed to provide adequate lateral support; but, on account of the open spaces necessary in the floors for elevators and other equipment, special bracing may be required. In order to prevent the moving of the caissons, caused by the deformation of the timber bracing, it is necessary to put initial compression into the struts by means of wedges. Frequently the structural-steel framing for the floors is so designed and detailed that it can be placed before the columns, and thereby can take the place of the temporary bracing with a resultant saving in cost.

When the excavation has been completed the dovetailed grooves at the caisson joints are cleaned out and filled with concrete. The hollow tile shown in Fig. 55 is provided to catch any water which penetrates the clay seal. This water is led to a sump and is disposed of by pumping.

Even though the walls are water-tight and although a water-tight joint is secured between the caissons and the bed rock, it is quite probable that water will work its way into the lower floor through fissures in the rock. By placing crushed rock or a system of drains under the lower floor, this water may be drained to a sump where it is easily disposed of by pumping into the sewers. If a water-tight membrane is used under the floor instead of drains, the floor must be designed to resist the uplift due to hydrostatic pressure.

If the lower floor is placed above the elevation of bed rock, the wells for the interior piers can be excavated without serious interference by water.

Well-Point Method. The well-point method for excavation in water-bearing material consists of surrounding the area to be excavated by a row of closely spaced well points placed along each side and of lowering the water table in that area by pumping the water through the well points. The excavation within the area can then be carried on in the dry. A well point is a pipe provided with a point at its lower end and with a screen or filter along the lower 3 or 4 ft. of its length. Some types of well points are designed for driving with a maul, whereas others are designed for jetting into position. The well points are set about 3 ft. apart, the top of each point being connected to a header pipe which is connected to a pump. The water level may be lowered as much as 20 or 30 ft. This method is used chiefly in trench excavation and in unwatering the whole area occupied by a building, but is also applicable to excavation for piers. It is usually necessary to provide sheathing to keep the banks from caving, but this does not need be water-tight.

ARTICLE 22. DRAINAGE OF FOUNDATIONS

The foundations of buildings are frequently provided with drainage systems to carry off ground water which may reduce the bearing power of the soil or may tend to cause damp or wet basements. These drainage systems may consist simply of a backfilling of loose rock to collect water which would otherwise come against the wall. It is provided with an outlet so that the water collected may drain away into a separate drainage line or, if permitted, into a sewer. The top foot or so of the backfilling is made of ordinary soil to permit planting and to keep surface water from entering the rock backfill. This type of drainage system is illustrated in Fig. 56*a*. Instead of relying on the rock drain just described to carry the water away, a line of sewer pipe laid with open joints is commonly installed next to the footings, as shown in Fig. 56*b*, or a drain consisting of a half tile on a concrete slab, as shown in Fig. 56*c*, can be used.

In the systems described there will usually be some water standing in the bottom of the trench which may decrease the bearing power of the soil. A more effective system consists of installing a drainage system in trenches located a few feet outside the area occupied by the

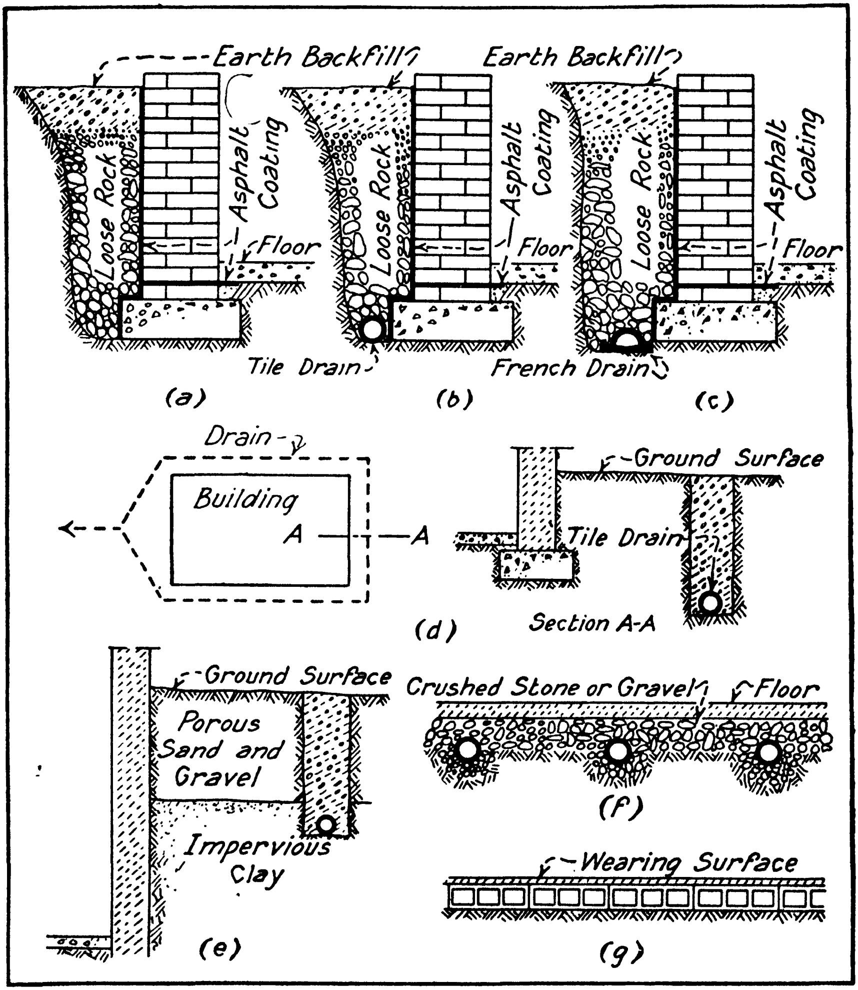


FIG. 56. Drainage of Foundations

building. These trenches are carried down well below the bottom of the footings and may surround the building; or, should underground water have a definite direction of flow, the trenches may often be necessary only on the upstream side of the building and the two adja-

cent sides, omitting the trench on the downstream side. These trenches are filled with rock and may be provided with a drain or sewer pipe laid with open joints; or, in some cases, the loose rock with which the trenches are filled is depended upon entirely to carry away the water. These systems are illustrated in Fig. 56*d*. The loose rockfill effectively cuts off all water from the building and the drain carries it away. The top 18 in. or 2 ft. of the trenches is filled with ordinary soil to keep surface water out of the trenches and to support vegetation.

Often ground water is present in a porous layer of gravel, under which there is a layer of impervious clay, as shown in Fig. 56*e*. Even though the foundations go well down into the clay, it may not be necessary to carry the drainage trenches to that depth. Under these conditions, trenches carried down about a foot into the clay, as shown in the figure, have effectively cut off all underground water. Seams of porous material in the clay may prevent this type of installation.

Basements are sometimes drained by a system of drains placed under the floor in a layer of crushed rock, gravel, or cinders, as shown in Fig. 56*f*. This system does not prevent water from soaking through the outside walls and is less effective than the methods just described. If an effective drainage system is placed outside the building, this interior drainage is unnecessary except where springs exist inside the building area.

In some cases a system of drainage for floors has been formed by placing a layer of hard-burned hollow tile under the floor and providing a wearing surface on the tile of cement mortar an inch or more in thickness. These tile are connected to a drain which conveys the water away. This method is illustrated in Fig. 56*g*.

In all the methods described it is necessary to dispose of the water collected in the drainage system by connecting the system to one or more drains which convey the water away to nearby streams, ravines, or low-lying ground. Frequently, the drains may be connected to the city storm sewer systems.

Sometimes where the amount of water is small and it is impossible to convey it away by gravity, the water may be collected in a *sump* from which it is pumped. Where the amount of water is large and can not be disposed of by gravity drainage, it is usually necessary to waterproof the basement, to keep the water out, and to permit the building to stand in water. Frequently, the lowest basement floor level is 20 or 30 ft. below the ground-water level. Under these conditions, it may be necessary to waterproof the foundation walls and the basement floor. The pressure of water must be considered in design. The methods used in waterproofing are described in Art. 23.

The use of water-tight caisson cofferdams is described in Art. 21 and is illustrated in Fig. 55.

Surface water may find its way into basements when the backfilling against the walls has been carelessly done. As a rule, this difficulty can be overcome by carefully tamping a layer of clay a few inches thick on the surface around the building. This layer should be 3 or 4 ft. wide. Frequently, basement floor drains and footing drains are combined in one system with a single outlet line running to a storm sewer. This is a satisfactory procedure if properly done. However, the common practice of connecting downspouts to this same outlet is objectionable because any stoppage or insufficient capacity beyond the junction will cause roof water to enter the basement.

ARTICLE 23. WATERPROOFING AND DAMPPROOFING

Methods of Waterproofing. Concrete walls are made water-tight in the following ways:

a. By using high-quality concrete.

b. By including substances in the concrete mixture to act as void fillers. Some of these are finely ground clay or sand, hydrated lime, chloride of lime, oil emulsions, and lime soaps. This is known as the *integral method.*

c. By coating the inside or outside surface with cement mortar, bituminous materials, or other substances which act as water seals.

d. By covering the outside surfaces with a membrane consisting of several layers of waterproofing felt cemented together and to the surface with bituminous material applied hot. This is called the *membrane method.*

It should be kept in mind that the walls are only one avenue by which the water may enter. If a structure is below the ground-water level, water will enter through the floor and will exert pressure, proportional to the depth of the bottom of the floor slab below the water level, against the floor.

The following material, except that on membrane waterproofing, is abstracted from recommendations in the 1940 Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete,* to which the reader is referred for more complete information.

Water-Tightness of Concrete. Good concrete is water-tight, for all practical purposes, even under high pressures. Leakage is due either to improper concrete practice or to the structural features such as cracks or joints. Leaks occur chiefly at planes of contact between successive

* Reference 10, p. 98.

lifts because of improper bond or from porous concrete at the top of the lift which is due to water gain. Another common cause of leakage is honeycomb or segregation occurring during placement. The prevention of such defects is the first step in water-tight construction.

Presence of Cracks and Joints. Even in the best of concrete, leakage may occur through expansion joints, construction joints, or cracks. Leakage through joints can be prevented by the use of *non-corrosive waterstops*. Cracks resulting from load, settlement, temperature changes, or shrinkage of concrete may cause leakage in a structure exposed to direct water pressure. Difficulties from this cause can be reduced by proper design, particular attention being paid to arrangement of contraction joints and proper distribution of reinforcement.

Importance of Drainage. Proper drainage is often the only precaution required; but in any case it is the first requirement, to which waterproofing is added as a further precaution.

Need of Some Type of Protection. If water stands against one side of a wall and the other side must be dry, some method of waterproofing may be necessary which takes into account the possibility of the occurrence of cracks or defective spots in the concrete. Some methods mentioned in the following paragraphs may be effective, or else membrane waterproofing may be required.

Dampproofing. Dampness on the interior surface of a wall may be due to water which penetrates the wall by capillary action, without actual flow of water under pressure. Condensation on the wall often occurs if there is a fall in temperature. The prevention of moisture penetration by capillary action is called *dampproofing,* in contrast to *waterproofing* which prevents the actual flow of water through a wall. The moisture which condenses on a wall may not necessarily have come through the wall. The condensation may occur on the wall merely because it is a cold surface. The remedy for dampness caused by capillary action is to seal the pores on the outside. Most methods used for waterproofing will also serve as dampproofing, but simpler methods may also be satisfactory. The use of a seal coat on the inside may be effective, but, if the wall is subjected to freezing temperatures, this method should not be used because the moisture trapped in the wall may freeze and damage the concrete.

Coatings on Side away from Water Pressure. Waterproofing is preferably applied to the side exposed to water pressure, but it may be necessary to depend on inside treatment. If the wall is not subjected to freezing temperatures the latter may be advantageous because sources of leakage are easier to detect and repair.

Waterproofing with Portland Cement Mortar. A properly applied and cured plaster coat of portland cement mortar on the outside of a wall is effective waterproofing unless the wall cracks. Such a coating may be effective on the inside also, even against considerable pressure. Cracks and defective spots are readily patched from the inside, even if there is actual flow of water. If the flow is considerable, an agent which will accelerate the setting of the cement may be necessary. In applying portland cement plaster to the inside or outside, the surfaces should be clean, the suction must be adequate, and the curing conditions favorable. The mortar should be about one part of cement to two parts of sand applied in at least two coats, each about $\frac{3}{8}$ in. thick. Powdered iron preparations containing some agent, such as ammonium chloride, to hasten oxidation of the iron may be effective if added to the mortar. The iron increases in volume upon oxidation and tends to fill the pores in the concrete.

Integral Waterproofing. The water-tightness of very lean concrete mixtures will be improved by the addition of almost any fine, inert material. The increased plasticity resulting from the use of this material will reduce segregation and improve workability. Rich mixtures are sufficiently plastic, and will not benefit in this way from the addition of powdered admixtures. Their quality and water-tightness are actually reduced because the powdered admixtures require an increase in the water content. Water-repellent admixtures reduce absorption and retard moisture penetration by capillary action, but are not effective against water under pressure. Some water-repellent admixtures may improve the workability of concrete and, thereby, the water-tightness against direct pressure.

Waterproofing with Surface Treatment. Some materials applied to the surface of concrete serve as waterproofing or dampproofing. Any cracks which may exist or develop in the wall will destroy, of course, the effectiveness of such waterproofing at these points, but such cracks are not so objectionable in dampproofing. Several kinds of *bituminous coatings* of asphalt or tar are available. Some are applied hot, and others are applied cold and harden by the evaporation of a liquefier. The effectiveness of such materials depends upon the materials themselves, upon the condition of the concrete, and upon the type of exposure. Mixtures of *pulverized iron* and cement, usually with an oxidizing agent for the iron, are used for waterproofing concrete surfaces. These are applied in a thin coating like paint, or with a stiffer consistency to produce a coating of measurable thickness. Many *proprietary materials* are available whose effectiveness can only be determined by experience.

Membrane Method. The membrane method of waterproofing consists of surrounding the entire surface, of the part of a building which is below water, with a waterproof membrane, as shown diagrammatically in Fig. 57*a*. This membrane consists of a bituminous material which cements together several layers of waterproofing felt, burlap, or canvas. The bituminous material may be coal tar, pitch, or asphalt, applied hot. The membrane method is applicable to all types of masonry including concrete.

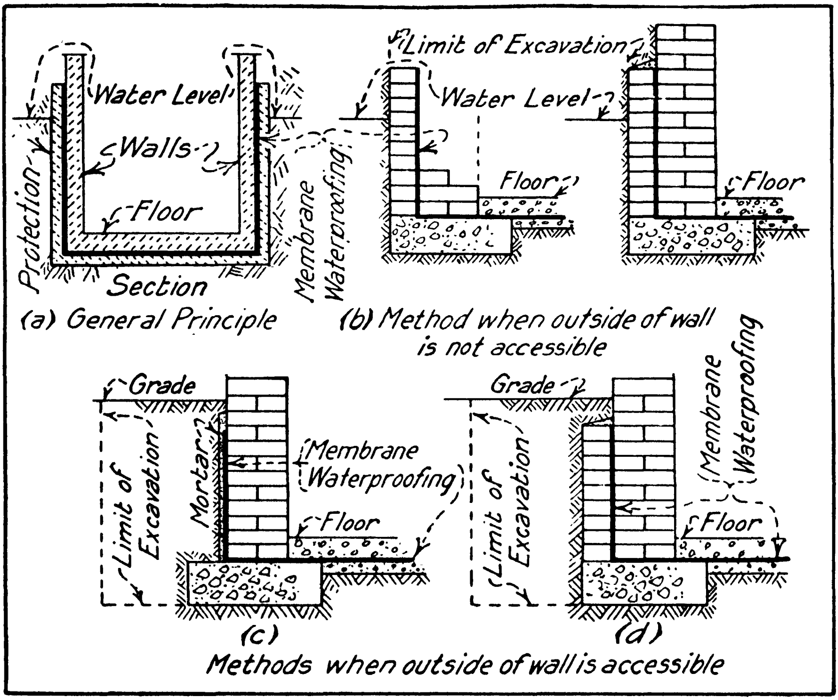


FIG. 57. Waterproofing of Foundations by Membrane Method

In order to produce successful results, the bituminous membrane must be absolutely continuous around the walls and under the floors. The membrane should be protected against injury by a layer of brick or concrete.

If the basement is not to be excavated far enough outside the building to permit the membrane to be applied to the walls from the outside, a 4-in. wall of brick may be built up outside of the wall line as shown in Fig. 57*b*. The membrane is applied to this wall, as shown in the figure, and the wall proper is built against the membrane. If the mem-

brane is applied from the outside it may be protected by a heavy coating of cement mortar, as shown in Fig. 57*c*, or by a 4-in. brick wall, as shown in Fig. 57*d*. By referring to Fig. 57*b* to *d* it will be noted that the floors are waterproofed by first placing a thin slab on a porous fill; the membrane is then placed on this slab, and a heavier slab is placed on top of the membrane. This top slab must be designed to carry the pressure due to the static head of the water which comes in contact with the floor.

The membrane method of waterproofing is the most reliable of any mentioned in this article. The membrane must be very carefully laid, for leaks are often due to poor workmanship and are very difficult to repair. The membrane, being elastic, will usually not be broken by expansion or settlement cracks.

REFERENCES

1. YOUNG, NATHAN: "Excavations: Rights and Liabilities of Owners, Contractors and Adjoining Owners," *Engineering News-Record*, p. 615, Apr. 10, 1930.

2. MCCULLOUGH, C. B.: "Highway Bridge Surveys," Technical Bulletin 55, U. S. Department of Agriculture.

3. MOHR, H. A.: "Exploration of Soil Conditions and Sampling Operations," Harvard University Bulletin 208, 1937.

4. SIMPSON, WILLIAM: "Foundations, Examination and Testing of Ground Preliminary to Construction of Works," Constable & Co., Ltd., 1928.

5. LEGGETT, ROBERT F.: "Geology and Engineering." McGraw-Hill Book Co., 1939.

6. CUEVAS, J. A.: "The Floating Foundation of the National Lottery of Mexico," *Proceedings of the International Conference on Soil Mechanics and Foundation Engineering*, Vol. I, 1936.

7. CASAGRANDE, A.: "Building Foundation Design," *Engineering News-Record*, Feb. 1, 1940.

8. *Engineering News-Record:* "Building on Soft Clay," Nov. 23, 1939.

9. CASAGRANDE, A.: "The Structure of Clay and Its Importance in Foundation Engineering," *Journal of the Boston Society of Civil Engineers*, April, 1932.

10. GLICK, G. W.: "Rigid Rectangular Frame Foundation for Albany Telephone Building," *Engineering News-Record*, Nov. 27, 1930.

11. GARLAND, KIMBALL R.: "Economics of Rigid Frames for Building Foundations," *Engineering News-Record*, Vol. 115, 1935.

12. GRIFFITH, JOHN H.: "Dynamics of Earth and Other Macroscopic Matter," Bulletin 117, Iowa Engineering Experiment Station, 1934.

13. CUMMINGS, A. E.: "Distribution of Stresses Under a Foundation," *Transactions of the American Society of Civil Engineers*, No. 101, 1936.

14. KRYNINE, D. P.: "Pressures Beneath as Spread Foundation," *Transactions of the American Society of Civil Engineers*, No. 103, 1938.

15. NEWMARK, N. M.: "Simplified Computations of Vertical Pressures in Elastic Foundations," Circular 24, Engineering Experiment Station, University of Illinois.

16. FABER, OSCAR: "Pressure Distribution Under Bases and Stability of Foundations," *Structural Engineer,* March, 1932.

17. ENGER, M. L.: "The Distribution of Pressure by Granular Materials," *Engineering,* Vol. 101, 1916.

18. KOGLER, F., and A. SCHEIDIG: "Druckverteilung im Baugrunde" (Pressure Distribution in Building Soil), *Bautechnik,* 1927, No. 29 and 31; 1928, No. 15 and 17; 1929, No. 18 and 52.

19. TERZAGHI, KARL VON: "Settlement of Structures," *Proceedings of the International Conference on Soil Mechanics and Foundation Engineering,* Vol. III, 1936.

20. TERZAGHI, CHARLES: "Science of Foundations," *Transactions of the American Society of Civil Engineers,* Vol. 93, 1929.

21. ENGER, M. L.: *Transactions American Society of Civil Engineers,* No. 85, p. 1581, 1922.

22. HOUSEL, W. S.: "A Penetration Method of Measuring Soil Resistance," *Proceedings of the American Society for Testing Material,* Vol. 35, 1935.

23. KREY, H.: "Erddruck, Erdwiderstand und Tragfahigkeit des Baugrundes," 1936.

24. TAYLOR, D. W.: "Stability of Earth Slopes," *Journal of the Boston Society of Civil Engineers,* July, 1937.

25. CUEVAS, JOSÉ A.: Discussion of "Movements in Foundation Pits During Construction," *Proceedings of the International Conference on Soil Mechanics and Foundation Engineering,* Vol. III, 1936.

26. TERZAGHI, KARL VON: "Settlement of Structures in Europe," *Transactions of the American Society of Civil Engineers,* Vol. 103, 1938.

27. "Timber Piles and Construction Timbers," *Manual of Engineering Practice,* 17, American Society of Civil Engineers, 1939.

28. DEAN, A. C.: "Piles and Pile Driving," Crosby Lockwood and Son, Ltd., 1935.

29. CUMMINGS, A. C.: "Pile Foundations," *Proceedings of the Purdue Conference on Soil Mechanics,* 1940.

30. PORTLAND CEMENT ASSOCIATION: "Concrete Piles," 1940.

31. PRENTIS, E. A., and LAZARUS WHITE: "Underpinning," Columbia University Press, 1931.

32. IMMERMAN, HARRY T.: "Concrete-Filled Steel Cylinders for Foundations," *Proceedings International Conference on Soil Mechanics and Foundation Engineering,* Vol. II., 1936.

33. DURKEE, E. L. and R. L. MCINTOSH: "Structural Steel Bearing Piles," *Journal of the Boston Society of Civil Engineers,* April, 1937.

34. WEST, OSCAR J.: "Cored-Out Pipe Piles Used in Sticky Clay," *Engineering News-Record,* Nov. 29, 1928.

35. MELICK, NEAL A.: "Cast-In-Place Concrete Pile Work in Quaking Clay," *Engineering News-Record,* May 23, 1928.

36. MCINTOSH, W. T.: "Extra Long Cylinder Piles Carry Column Loads to Rock," *Engineering News-Record,* July 7, 1932.

37. CHAMBERS, RALPH H.: "Survey of Foundation Construction Methods," *Civil Engineering,* January, 1941.

38. UPSON, MAXWELL M.: "Recent Developments in Pile Foundations," *Journal American Concrete Institute,* May–June, 1937.

39. CRANDALL, J. STUART: *Transactions of the American Society of Civil Engineers,* No. 103, p. 1233, 1938.

40. MILLER, R. M.: "Soil Reactions in Relation to Foundation Piles," *Transactions of the American Society of Civil Engineers*, No. 103, p. 1236, 1938.

41. BENNETT, RONALD: "Pile-Driving and the Supporting Capacity of Piles," Selected Paper 111, Institution of Civil Engineers, 1931.

42. DEAN, A. C.: "Piles and Pile Driving," Crosby Lockwood & Son, Ltd., London, 1935.

43. CUMMINGS, A. E.: "Dynamic Pile Driving Formulas," *Journal of the Boston Society of Civil Engineers*, January, 1940.

44. Uniform Building Code: Pacific Coast Building Officials Conference, 1940.

45. TERZAGHI, KARL VON: "Soil Mechanics—A New Chapter in Engineering Science," *Journal of the Institution of Civil Engineers*, 1938–1939.

46. "Proposed Building Code for City of Boston," 1937.

47. SMITH, AARON J.: "Rotary Drill Bores Holes for Timber Piles in Clay," *Engineering News-Record*, Aug. 4, 1932.

48. WEST, OSCAR J.: "Cored-Out Pipe Piles Used in Sticky Clay," *Engineering News-Record*, Nov. 29, 1928.

49. UPSON, M. M.: "Concrete Piles and Piling Construction," *Proceedings of the Engineers' Society of Western Pennsylvania*, Vol. 40.

50. CHRISTINE, H. A.: "Boring Machine Digs Wells for Concrete Piers," *Engineering News-Record*, July 28, 1932.

51. JACOBY, H. S., and ROLAND P. DAVIS: "Foundations of Bridges and Buildings," McGraw-Hill Book Co., 1914. Third Edition, 1941.

52. *Engineering News-Record*: "Rotating Foundation Caissons Drill Their Way to Rock," July 11, 1935.

53. BOWEN, S. E.: "Sinking Open Concrete Caissons for Foundations," *Engineering News-Record*, Dec. 13, 1928.

54. *Construction Methods*: "Open Steel Caissons Driven Through Water-Bearing Rock Fill," March, 1935.

55. MCINTOSH, W. T.: "Unusual Foundation Procedure for 71-Story Building," *Engineering News-Record*, Apr. 24, 1930.

56. WOLFE, W. S.: "Unusual Foundation Design for Tall Steel Building," *Engineering News-Record*, May 2, 1929.

57. STROYER, R.: "Concrete Structures in Marine Work," Knapp Drewett and Sons, Ltd., London.

58. *Construction Methods*: "Rotary Drills Speed Caisson Shaft Construction in Wet and Dry Soils," November, 1932.

59. *Engineering News-Record*: "Jetted-Casing Method Employed for Caisson Excavation," Jan. 28, 1932.

60. *Engineering News-Record*: "Corrugated Steel Shells in Bored Holes," Sept. 4, 1930.

61. THOMPSON, T. KENNARD: "Caisson Cofferdam Foundation," *Engineering News-Record*, Vol. 88, p. 914.

62. TERZAGHI, KARL VON: "Settlement from Excavation," *Engineering News-Record*, Feb. 1, 1940.

63. CUEVAS, JOSÉ A.: "Foundation Conditions in Mexico City," *Proceedings of the International Conference on Soil Mechanics and Foundation Engineering*, Vol. III, 1936.

64. WOOLTORTON, D.: "A Preliminary Investigation into the Subject of Foundations in the 'Black Cotton' and 'Kyatti' Soils of the Mandalay District,

Burma," *Proceedings of the International Conference on Soil Mechanics and Foundation Engineering,* Vol. III, 1936.

65. SIMPSON, W. E.: Discussion of reference 64.

66. TAYLOR, D. W., and W. MERCHANT: "A Theory of Clay Consolidation Accounting for Secondary Compression," *Journal of Mathematics and Physics,* Vol. XIX, No. 3.

67. TERZAGHI, KARL VON: "Design of Pile Foundations," Fourth Texas Conference on Soil Mechanics and Foundation Engineering, University of Texas, 1941.

68. BURMISTER, D. M.: "Stress Distribution for Pile Foundations," *Proceedings of Purdue Conference on Soil Mechanics,* 1940.

69. Progress Report of Committee on Bearing Value of Pile Foundations: "Pile-Driving Formulas," *Proceedings of American Society of Civil Engineers,* May, 1941.

70. KRYNINE, DIMITRI P.: "Soil Mechanics," McGraw-Hill Book Co., 1941.

71. TERZAGHI, KARL: "Theoretical Soil Mechanics," John Wiley and Sons, 1943.

CHAPTER IV

MASONRY CONSTRUCTION

ARTICLE 24. DEFINITIONS AND GENERAL DISCUSSION

The walls of a building may have many functions. They may be used simply for inclosing the building or parts of the building. They may be required to carry their share of the weight of the buildings and contents, they may carry only their own weight, or they may be carried by the structural frame. They are required to keep out rain, to resist the transmission of heat and sound, and to resist fire. On account of their many functions, walls are divided into a large number of classes. The names which are applied to the various classes of walls are not standardized and vary somewhat in different parts of the country. These differences will be noted in the classification given in the next paragraph.

Classes of Walls. Walls are divided into many different classes depending upon their positions, functions, and type of construction.

A *bearing wall* is one which supports any vertical load in addition to its own weight.[1]

A *non-bearing wall* is one which supports no load other than its own weight.[1]

A *panel wall* is a non-bearing wall in skeleton construction, built between columns or piers and wholly supported at each story. This type of wall is also called a *filler wall*, a *curtain wall*, and an *inclosure wall*.

An *inclosure wall* is an exterior non-bearing wall in skeleton construction, anchored to columns, piers, or floors, but not necessarily built between columns or piers.[1] It may be supported at each story or at intervals of two or more stories, as best suits the design; it is not the same as a panel wall, which must be wholly supported at each story.

A *curtain wall* is a non-bearing wall between columns or piers and is not supported by girders or beams.[1] Many building codes apply the term curtain walls to walls of the type indicated in panel wall defined above.

A *spandrel wall* or *spandrel* is usually considered a panel wall below the windows which fill practically the entire space between columns, but some apply this term to the portion of a panel wall between the top of a window and the floor construction above. See Fig. 58*a*.

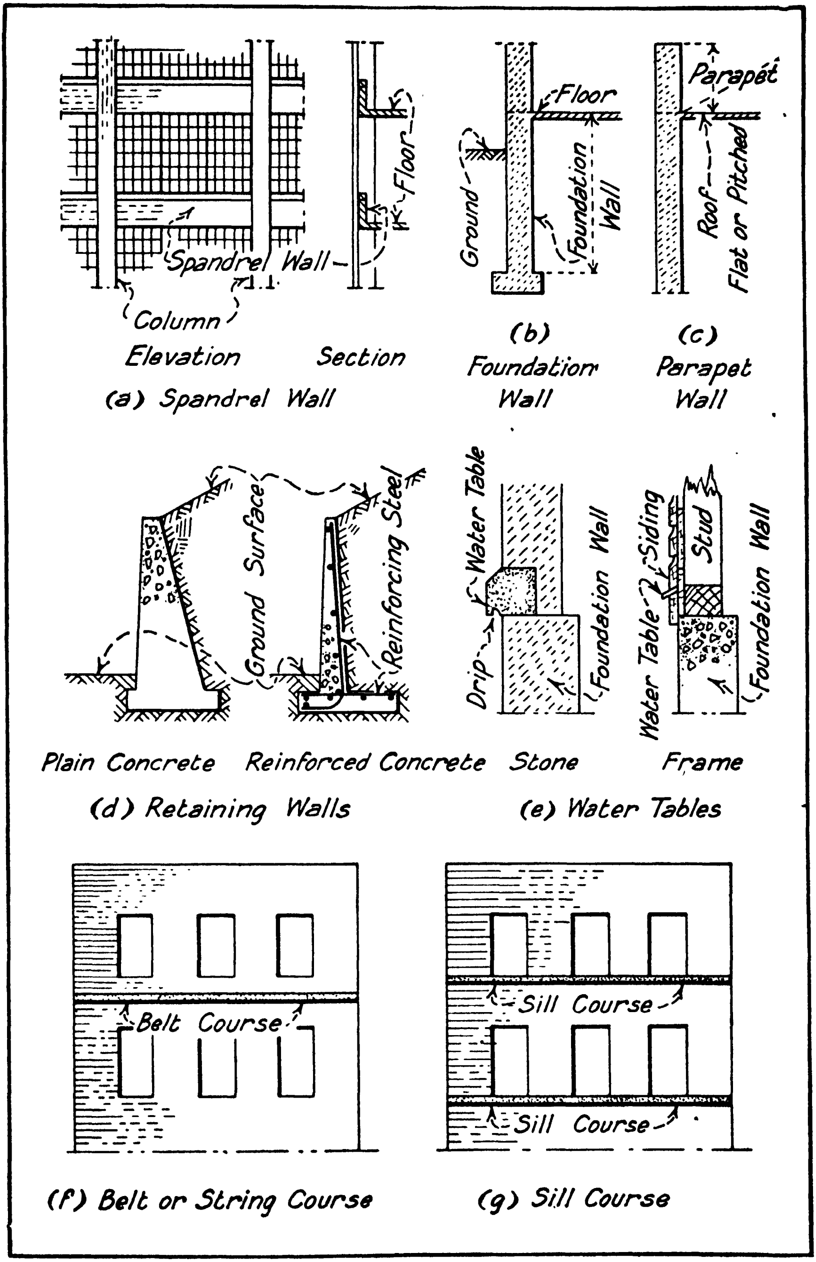


FIG. 58. Walls and Parts of Walls

An *apron wall* is a less common term for a spandrel wall and applies only to the portion of the wall between the sill and the floor line or, according to some codes, between the head of the windows of one story and sills of the next story.

A *parapet wall* is that portion of any wall which extends above the roof line and bears no load except as it may serve to support a tank. See Fig. 58*c*. Also called a *parapet*.

A *party wall* is a wall used or adapted for joint service between two buildings.[1]

A *foundation wall* is a wall built below the ground level, the curb level, or below the floor line nearest the ground level. See Fig. 58*b*.

A *dead wall* or *blank wall* is a wall without openings.

A *division wall* is any wall in the interior of a building.

A *partition wall* is the same as a division wall.

A *partition* is the same as a partition wall.

A *bearing partition* or *bearing partition wall* is one which carries a load in addition to its own weight.

A *non-bearing partition* is one which carries only its own weight.

A *fire wall* is one which subdivides a building to restrict the spread of fire, by starting at the foundation and extending continuously through all stories to and above the roof.[1] Fire walls are used in ordinary construction and in slow-burning or mill construction where the floors can not be depended upon to resist the full duration of a fire and are liable to collapse, or where beams and girders depend upon such walls for support. Buildings of skeleton construction do not use self-supporting fire walls extending from the foundation upward, as defined above, but employ walls supported by the structural frame or floor system in each story. Such walls are termed *fire-division walls* by the Building Code Committee of the Department of Commerce.

A *fire-division wall* is a wall which subdivides a fire-resistive building to restrict the spread of fire, but is not necessarily continuous through all stories nor extended through the roof.[1]

A *retaining wall* is one whose chief function is to resist the lateral pressure of earth or a similar material. See Fig. 58*d*.

A *solid masonry wall* is one consisting of solid masonry units laid up with joints filled with mortar and without air spaces between the units.

A *hollow wall* is one built of solid masonry units so arranged as to provide an air space within the wall.

A *hollow masonry wall* is one consisting wholly or in part of hollow masonry units laid up with joints filled with mortar and without air spaces between the units.

Parts of Exterior Masonry Walls. The following definitions include various elements which may be considered as parts of an exterior wall.

The *foundation* is the structure at the bottom of a wall, designed to transmit the load carried by the wall to the earth. This may be some form of footing or a more elaborate foundation as described in Chapter III.

The *foundation wall* is the part of the wall below the surface of the ground and resting on the foundation.

The *water table* is a slight projection on the outside of a wall near the ground. In some cases, the water table serves to deflect the water passing over the wall surface so that it will not follow down the foundation wall. See Fig. 58*e*.

A *course* is a continuous horizontal layer of brick, stone, or similar material, consisting of blocks and forming part of a wall.

A *withe* or *wythe* is a vertical layer of brickwork one brick width in thickness. Also called a *tier*.

The *base course* or *plinth* is usually a course of stone placed just above the ground level. A variety of stone is chosen which will resist the severe weathering action which occurs at this point.

A *belt course* or *string course* is a horizontal band which runs across the face of a wall, flush with the wall surface or projecting, and either plain or molded. See Fig. 58*f*.

A *sill course* is a belt course which serves also as sills for window openings. See Fig. 58*g*.

A *sill* is the member at the bottom of a window or door opening. See Fig. 59*a*.

The *jambs* are the sides of a window or door opening. See Fig. 59*a*.

The *head* or *cap* is a member at the top of a window or door opening. See Fig. 59*a*.

Quoins are blocks of stone forming external corners of walls. See Fig. 59*c*. Brick used in a similar position may also be called quoins.

The *cornice* is the projection at the top of a wall. See Fig. 59*d*.

The *coping* is the top cap or top course of a wall, designed to shed water, to protect the top of the wall, and to give a finished appearance to the top of the wall. See Fig. 59*c* and *e*.

A *corbel* is a horizontal projection on the face of a wall, formed by one or more courses each projecting over the course below.

A *gable* is the triangular-shaped piece of wall, closing the end under a gable roof. See Fig. 59*d*.

A *saddle stone* or *apex stone* is the stone at the junction of the two inclined copings of a gable. See Fig. 59*d*.

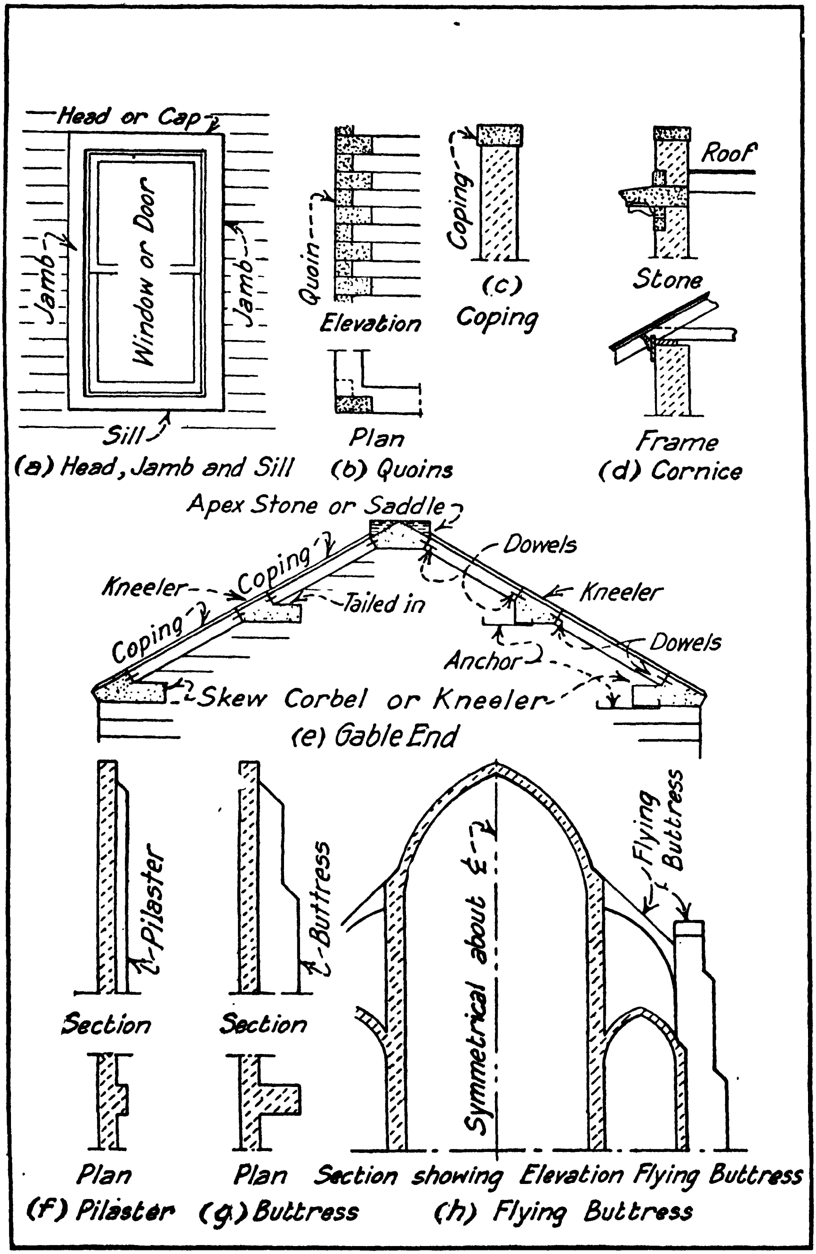


FIG. 59. Parts of a Wall

A *kneeler* is a coping stone, built securely into a gable wall to resist the sliding tendency of inclined coping. See Fig. 59*d*.

A *skew corbel* is a stone at the lower end of an inclined coping and is designed to resist the sliding tendency of the coping. See Fig. 59*d*. This is also called a *kneeler*.

A *reveal* is the part of a jamb which is exposed between the frame and the face of the wall. See Fig. 72.

A *wainscot* is a lining placed on the lower 3 to 5 ft. of inside walls and partitions for protection or decorative effect. It is made of wood, tile, marble, terrazzo, terra cotta, linoleum, or other materials. Also called a *dado*.

A *pier* is a relatively short, vertical prism of masonry. It may be built up independent of other masonry, in which case it is referred to as an *isolated pier;* it may be a vertical projection on the face or back of a wall to support one end of a truss or girder or to increase the lateral rigidity of the wall, in which case it is called a *wall pier*, an *engaged pier*, a *pilaster*, or a *buttress*; or it may be a short section of a wall between two openings and supporting the masonry extending over the openings.

A *pilaster* is a small vertical projection on the face of a wall to increase the rigidity or to take the reaction of a girder or truss. See Fig. 59*f*. It is sometimes called a *pier*, a *wall pier*, or an *engaged pier*. See definition of pier.

A *buttress* is similar to a pilaster but has a greater projection. See Fig. 59*g*.

A *flying buttress* consists of a masonry pier placed at some distance from a wall and connected to it by an inclined arch. Flying buttresses are more effective than buttresses in transmitting arch thrusts to the ground. See Fig. 59*h*.

Flying buttresses were developed in the construction of Medieval Gothic cathedrals to take the thrust of the vaulted roofs constructed of stone. Modern methods of construction do not make use of the flying buttress but it is still retained as an element in architectural design.

The *face* of a wall is the outside surface. The *facing* is the material which forms the face.

The *back* is the inside surface of the wall. The *backing* is the material between the facing and the back.

Parts of a Masonry Arch. The parts of a masonry arch are indicated in Fig. 60 and may be defined as follows:

The *arch ring* is the curved ring of masonry forming the arch.

The *span* is the width of the opening.

The *rise* is the height of the curved portion of the opening.

The *soffit* is the concave or lower surface of the arch ring.

The *back* is the convex or upper surface of the arch ring.

The *faces* are the exposed vertical planes or sides of the arch ring.

The *intrados* is the line of intersection of the soffit and a vertical plane parallel to the faces.

The *extrados* is the line of intersection of the back and a vertical plane parallel to the faces.

The *springing* lines are the lines of intersection or tangency of the soffit and the vertical, or nearly vertical, sides of the opening.

The *crown* is the highest part of the arch ring.

The *spandrel* is the space between the back of the arch ring and a horizontal plane tangent to the back of the arch ring at the crown.

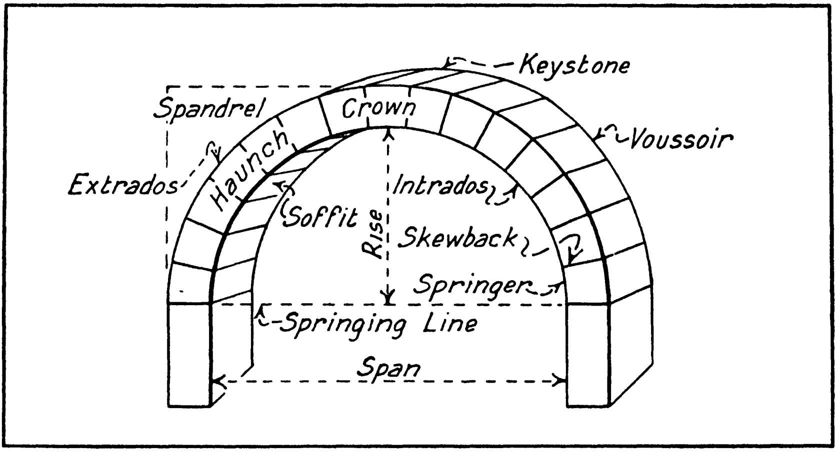


FIG. 60. Parts of an Arch

The *voussoirs* are the blocks of masonry of which the arch ring is composed.

The *keystone* is the voussoir at the crown.

The *springers* are the voussoirs just above the springing lines.

The *haunches* are the sides of the arch ring.

The *skewbacks* are the upper surfaces of the springers.

The *abutments* are the masses of masonry at the sides of the opening which resist the thrust of the arch. Masonry arches which are a part of a wall do not have well-defined abutments, for the wall itself serves in this capacity.

An *arcade* is a series of arches and includes the supporting members between the arches, such as piers, columns, etc.

Curve of Arch Ring. Many curves and combinations of curves are used in laying out arches. When strength and economy of material are important factors, as they are in arch bridges, the curve of the arch ring is determined by the span and rise of the arch and the characteristics of the loading; but, for the ordinary arches over openings of the walls of buildings, appearance is more of a factor in design than strength and economy of material. The most common cause of the failure of arches used in building construction is the spreading of the abutments or the masonry which serves as abutments. This condition exists when arched window or door openings are placed too near the wall corners and the abutments at the ends of the arcade are insufficient.

Types of Arches. The curve of the intrados is commonly a portion of the arc of a circle or a combination of the arcs of various circles with different radii and centers. Four types which have one center, as shown in Fig. 61*a*, are the *semicircular*; the *segmental*, which includes less than a semicircle; the *horseshoe*, which includes more than a semicircle; and the *stilted*, which consists of a semicircular-arch ring with straight vertical sections added on each side.

Two-centered arches are shown in Fig. 61*b*. The three types, i.e., blunt, equilateral, and lancet, differ only in the relation between the radius and the spacing of the centers. In the *blunt* or *drop arch* the centers are within the arch. In the *equilateral* or *Gothic arch* the radius of the intrados equals the span, and the centers are therefore on the springing lines. The centers for the *acute* or *lancet arch* are outside the arch.

There are two types of three-centered arch, as shown in Fig. 61*c*. In the first, one center is used for the arc of the central portion of the arch and two centers for the arcs at the ends of the arch ring. In the second, one center serves for the two arcs at the ends of the arch ring and two centers are required for the central portion of the arch ring.

The four-centered or *Tudor arch*, as shown in Fig. 61*d*, is similar to the second type of three-centered arch, but the centers for the lower section of the arch ring do not coincide as in the three-centered arch. The vertical alignment of centers, as shown in the figure, is not essential to this type.

The *flat arch*, as shown in Fig. 61*e*, may be supported by arch action but it is usually carried on a concealed lintel.

The *two-cusped arch* is illustrated in Fig. 61*f*. Many forms of cusped arch have been used for decorative effect. They are very inefficient structurally.

The *elliptic arch* is similar in shape to the three-centered arch shown in Fig. 61*c*, but the curve of the intrados is a semiellipse.

The *parabolic arch* is similar in shape to the three-centered arch shown in Fig. 61*c*, but the curve of the intrados is a parabola with its axis vertical.

Groined arches are arches which intersect each other.

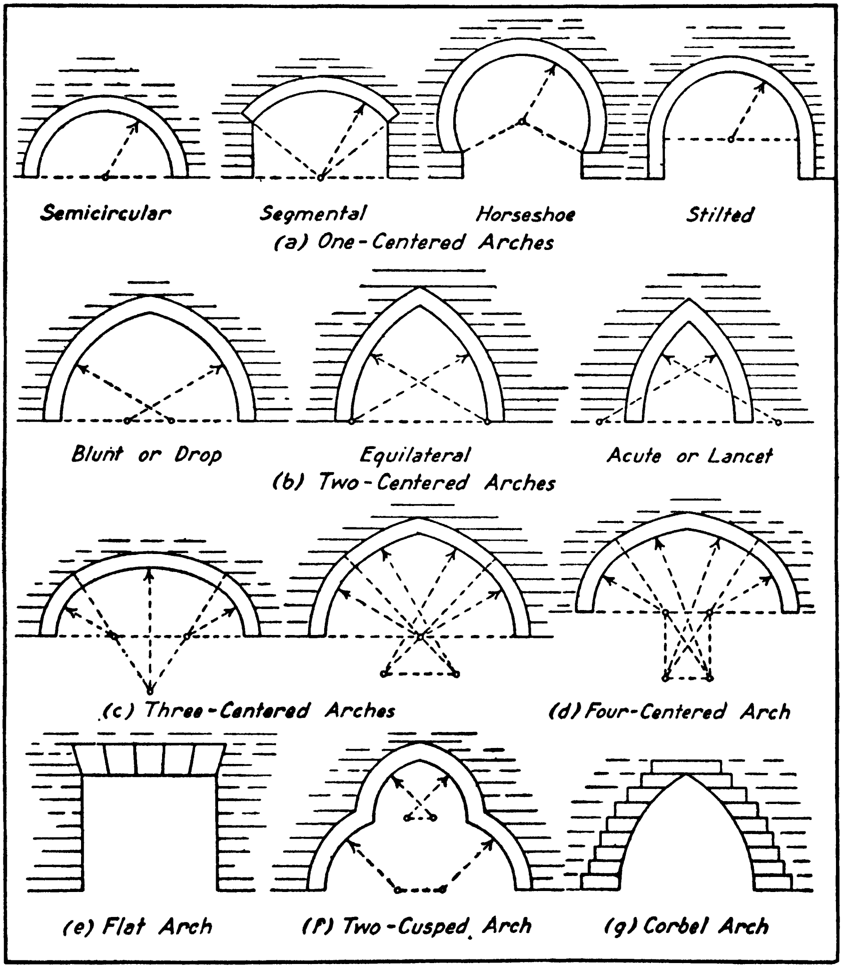


FIG. 61. Types of Arches

The *corbel arch*, shown in Fig. 61*g*, is not really an arch but is called an arch because of its shape. There is no real arch action, each course being corbeled or cantilevered out over the course below until the two sides meet.

Wall Furring. In general, *furring* consists of a light frame of wood or metal strips called *furring strips* applied to a surface to support plaster, stucco, or other surfacing material. It may be used to form an even surface over a rough or irregular wall or structural form; to form a hollow frame on which an imitation column, vault, or other decorative feature of plaster is placed; or to provide an air space between the rough inner surface of an outside wall and the finished surface of plaster or other finishing material. This is called *wall furring.*

Wall furring has three functions:

1. The air space intercepts any moisture which might pass through an outside wall and which would damage the wall finish and decorations and cause unwholesome living conditions.

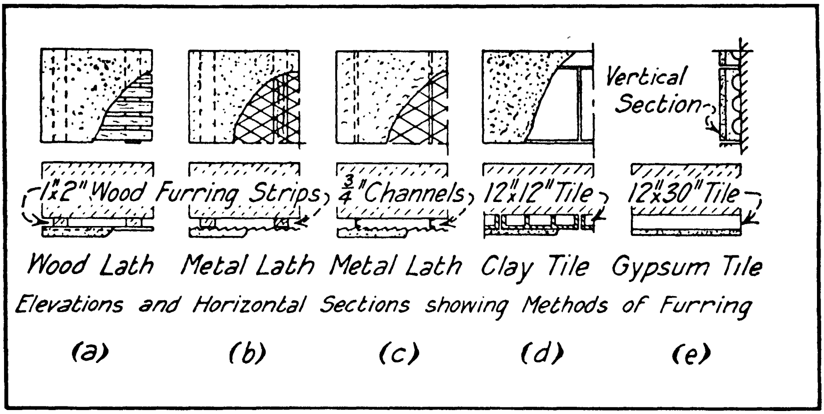


FIG. 62. Wall Furring

2. If humid air in a building comes in contact with a cold wall, there will be condensation on the wall which will be just as objectionable as having water pass through the wall. The air space acts as an insulator and prevents condensation.

3. The insulating properties of the air space reduce the heat transmission through a wall and thereby save fuel in cold weather and keep a building cooler in hot weather.

There are two general methods for furring. One consists of lath and plaster placed on vertical furring strips fastened to the wall. The other consists of applying specially designed blocks of hollow clay tile or gypsum to the wall. The blocks are coated with plaster after being placed. The use of wood lath on wood furring strips is illustrated in Fig. 62*a*, metal lath on wood furring strips in Fig. 62*b*, and metal lath on metal furring strips in Fig. 62*c*. Hollow clay furring tile, as shown

in Fig. 62*d*, are fastened to masonry walls by driving nails in the mortar joints and hooking the heads over the tile. The gypsum blocks shown in Fig. 62*e* are applied in the same way.

The following comments on furring are quoted from the "Recommended Minimum Requirements for Small Dwelling Construction" by the Building Code Committee of the Department of Commerce and are applicable to all classes of buildings.

1. In regions subject to low temperature, high winds, heavy rains, or extreme humidity of considerable duration, furring of solid masonry exterior walls is practically a necessity to avoid unwholesome living conditions caused by damp walls, and the danger of ruining wall decorations.

2. In arid localities, where low temperatures are infrequent, furring may be omitted without serious results, but should be used wherever economy in construction cost is a secondary consideration.

3. Waterproof paints or compounds applied to the interior of solid masonry walls help considerably to prevent moisture penetration, but have little effect on preventing condensation, and make it difficult to bond plaster to such treated walls.

4. Furring is somewhat less necessary on masonry exterior walls of hollow units, since the enclosed air cells help to check transmission of heat and moisture. However, mortar joints running through the wall are found to conduct moisture readily when poorly or incompletely made, and walls having such continuous joints require furring.

5. Furring a masonry wall lessens its heat conductivity, thus saving fuel, which saving, of course, continues throughout the life of the structure and may repay many times over the increased cost of furring.

6. Since hollow walls are good heat insulators, it has been found in many places that furring may be omitted and plaster applied directly to the interiors of the walls which are built with a continuous hollow space, or in which the mortar joints extend but part way through the wall.

7. In concrete house construction provision for insulation of exterior walls is recommended. A dead-air space within the wall itself or formed by furring and plastering has been found effective and this requirement seems to be favored by those recommending the use of concrete external walls.

In applying plaster to furring lath, it is important that the keys shall not project through so as to touch the wall, or be allowed to drop off and form a solid mass between the plaster and the wall. In either case moisture from the wall is liable to be transmitted through the plaster producing troublesome results, such as staining the wall, and ruining the lath — wood lath by dry rot and metal lath by corrosion. It is claimed that excellent results in furring 8-in. brick walls are obtained by attaching a layer of tarred paper to the back of the furring strips, or by using a lath of which such paper forms an integral part. Hollow tile or gypsum furring blocks are much used and are quite satisfactory. They have grooves in the back face which furnish air spaces

between the wall and the plaster. There are also several forms of metal furring to which metal lath is attached and which serve the same purpose. Where walls are likely to be continuously damp, hollow tile furring will be more satisfactory than gypsum.

To prevent the passage of fire from floor to floor behind the furring, it may be necessary to corbel the masonry walls, as shown in Fig. 63. This is not necessary if fireproof floors, coming in close contact with the walls, are used.

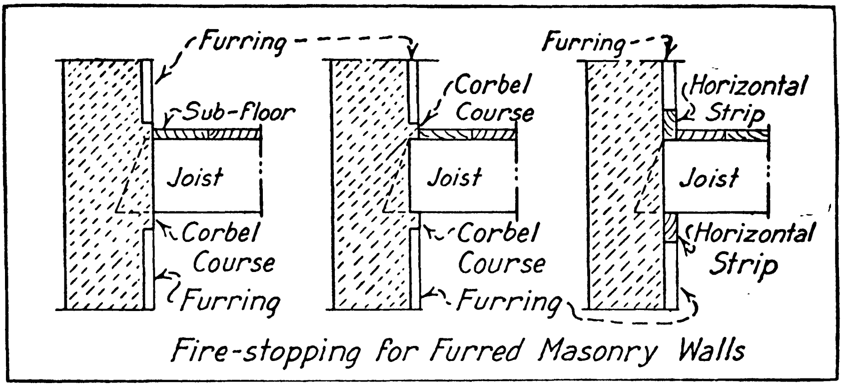


FIG. 63. Fire-Stopping for Wall Furring

Moisture Penetration. Construction to reduce or eliminate the penetration of rain water into masonry walls is a very important consideration. This factor has been investigated by the Bureau of Standards and the results of its tests are summarized as follows:[3]

The performances of the walls in the water-penetration tests depended more upon the quality of the workmanship than upon any other factor. Walls of brick having the interior joints well filled with mortar usually gave excellent performances, whereas those with poorly filled joints leaked. Aids in obtaining walls resistant to moisture penetration were the use of mortars of medium or high water retentivity, the wetting of absorptive brick before use, and the application of a parging of mortar on the back of the facing wythe. The omission of two-thirds of the normal number of header brick, or the insertion of a limestone sill or belt course had no important effect on the permeability of the walls. On the average, walls with a brick facing and a backing of hollow masonry units were slightly less permeable than brick walls of equal thickness when the joints were not well filled. When the joints were well filled the performance of walls with hollow units was somewhat superior in the capillarity test but inferior in the heavy-rain test to that for otherwise similar all-brick walls. The performances of walls of structural clay tile faced with

portland-cement stucco was somewhat better than the average for the walls of brick. The filling of openings in the joints with mortar, grout, or wax was effective in stopping leakage. Applications of colorless waterproofing solutions did not stop leakage through openings in the joints, but were effective in improving the performance of walls of absorptive brick when the openings in the joints had been sealed. Coatings of molten paraffin, oil paint, and cement paint were effective in reducing moisture penetration.

Flashing and Calking. Flashing and calking, or caulking, are important factors in reducing rain-water penetration into masonry walls and in reducing the harmful effects of water which does penetrate. Water which penetrates the outer layer of face brick or stone may pass through the wall or may flow downward through the joints and between the layers until it finds an outlet over a door, window, or other opening. This condition may be especially bad over bay windows or where an exterior wall becomes an interior wall owing to an extension of the building in the lower stories. The reduction in the amount of water penetration by proper selection of materials and good workmanship is considered in the preceding paragraph. Flashing and calking are used as an additional precaution at critical locations, such as under the copings on parapet walls and chimney tops, under window sills, over and under projecting belt courses. The function of calking is always to exclude water, but flashing may have the additional function of conducting water outward so that its effects will be less harmful. This is particularly true over openings in a wall. Typical uses of flashing and calking are illustrated in Fig. 64.[4]

The materials used for flashing are metal sheets of copper, lead, zinc, aluminum, galvanized iron, and tin plate; bituminous roofing papers; and copper-backed paper. The material selected in any case should be appropriate for the quality of the construction, keeping in mind that it is much more expensive to replace defective flashing than to install high-quality flashing initially.[5]

Calking consists of filling joints or cracks in the exterior of a wall and around door and window frames with thick ribbons of plastic calking material resembling soft putty. *Calking* is applied by extruding from a calking gun through a nozzle about ¼ in. in diameter and moving the gun along to form the ribbon. A good calking compound will adhere to the surfaces with which it comes in contact, will harden slowly, shrink very little, and not stain. Calking compounds differ considerably in composition but most of them consist of finely ground and fibrous materials, called pigments, mixed with a vehicle consisting of a drying or semi-drying oil and some volatile thinner. The finely ground material is usually calcite but quartz, dolomite, and other materials are

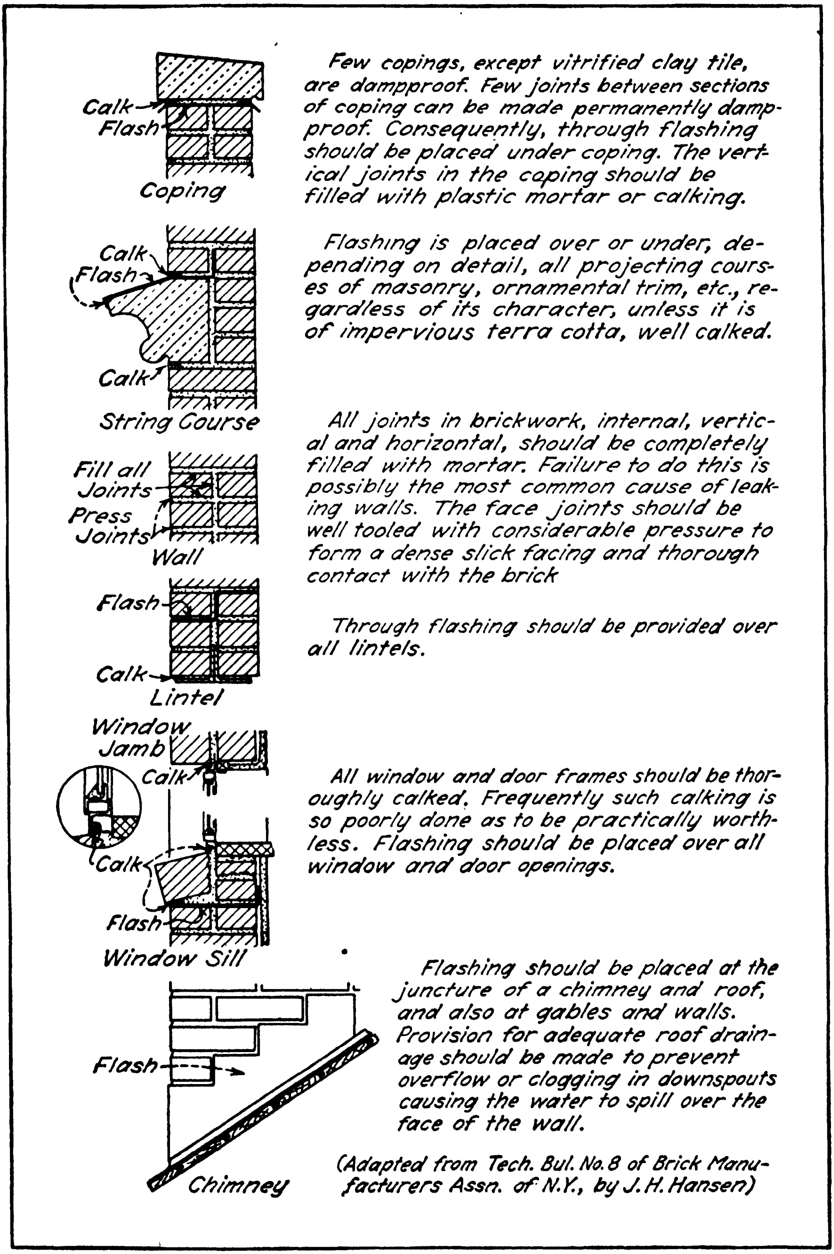


FIG. 64. Flashing and Calking

used. The fibrous material is usually asbestos. The oils most commonly used are fish, soybean, linseed, and tung. The thinner is usually mineral spirits. See Art. 93 and 94.[17]

Factors Affecting Wall Thickness. The principal factors which are commonly considered as affecting the thickness of masonry walls used in building construction are:

1. Loads to be carried.
2. Resistance to fire.
3. Kind and quality of the material used.
4. Character of occupancy.
5. Function of wall.
6. Height of wall above section considered.
7. Story height.
8. Spacing of buttresses and cross walls.
9. Window and door openings, chases, recesses, etc.
10. Span of beams bearing on wall.
11. Bond between face and backing.

Each of these items will be discussed in detail.

Building codes specify the minimum thickness which will be permitted under any circumstances. They also specify requirements which must be met in order that the minimum wall thickness may be used and they give allowable working stresses which may make it necessary to use thicknesses greater than the minimum in order to carry the loads to which the walls are subjected. The building codes of the various cities give the requirements which must be met for the plans of a building to receive the approval of the building departments and for the completed building to be acceptable to those departments. The engineer or architect may adopt requirements which are more severe than those of the building code, but he must not be less severe.

The discussion concerning masonry walls is based quite largely on the following: the Report of the Building Code Committee of the Department of Commerce entitled " Recommended Minimum Requirements for Masonry Wall Construction ";[1] the Building Code recommended by the National Board of Fire Underwriters;[2] and the building codes of various cities.

Loads. Masonry walls must be of sufficient thickness to carry the loads due to their own weight, the loads which are transmitted to them by the floors and the roof, and the loads due to wind and earth pressure without exceeding the specified working stresses. Building codes specify the live loads to be used for various classes of occupancy as described in Art. 3.

Kind and Quality of Material. Masonry walls are constructed of the following materials: brick, stone, hollow clay tile, concrete block, glass block, concrete, and various combinations of these materials.

In considering the requirements for walls of various materials, two factors must be taken into account, i.e., the strength and the stability of walls constructed of each material. For example, where strength is a controlling factor, ashlar stone walls may be made thinner than brick walls; but, where the stresses in the materials are low and stability is the important factor, the two materials are considered equivalent.

The quality of the materials is controlled by specifications and tests. The engineer or architect may write his own specifications for materials but, in general, the specifications of recognized authorities should be used. The American Society for Testing Materials has prepared specifications for a large number of structural materials and these specifications should be adopted wherever possible. Other organizations have prepared specifications which may be considered standard. The building code for each city specifies the minimum requirement for the quality of the materials for use in that city.

The stresses to which materials may be subjected safely are called *working stresses.* Codes and specifications give the working stresses for masonry walls of various materials.

Fire-Resistance Ratings. The fire-resistance ratings of walls and partitions of various types are given in the accompanying table. These are taken from the 1940 Building Code of the Pacific Coast Building Officials Conference. Corresponding ratings, which differ somewhat, are given in " Recommended Minimum Requirements for Fire Resistance of Buildings " (Report of the Building Code Committee of the Department of Commerce, 1931). The plaster called for in this table is gypsum or portland-cement plaster applied to an average of not less than $\frac{1}{2}$ in. on each side. Plaster over 1 in. thick, as measured to the plaster base, must have an additional layer of metal lath or wire or metal mesh embedded not more than $\frac{3}{4}$ in. from the surface and securely tied into the supporting members. The substitution of gypsum plaster board or lath for metal lath is permitted under certain conditions given in the Pacific Coast Building Officials Conference Code. The basis for fire-resistive ratings is discussed in Art. 2.

There are three factors which must be considered in connection with the fire resistance of walls. The material of which the wall is constructed must be fire resistive; the walls must be thick enough to prevent the transmission of heat to such an extent that the structure or contents of adjoining buildings may be damaged; and the walls must

be thick enough to resist satisfactorily the tendency to bulge and collapse during severe fires. In the following table are given the fire ratings for bearing and non-bearing walls of various materials and thicknesses.

RATED FIRE-RESISTIVE PERIODS FOR VARIOUS WALLS AND PARTITIONS

(1940 Uniform Building Code, Pacific Coast Building Officials Conference)

Minimum finished thickness, face to face in inches, including plaster where mentioned. Thicknesses of non-bearing walls and partitions are in italics.

Type of Wall	4 hr.	3 hr.	2 hr.	1 hr.
Brick of Clay, Shale, Sand Lime, Concrete or Plain Concrete				
Solid, unplastered	8			*4*
Solid, plastered	9		*5*	
Hollow (rowlock), unplastered	12	10	8	
Hollow (rowlock), plastered	9			
Hollow Clay Tile Wall — End or Side Construction				
One cell in wall thickness, plastered				*3*
Two cells in 8 in. or less thickness, unplastered	16	12		8–*6*
Two cells in 8 in. or less thickness, plastered	13	9	*7*	
Hollow Clay Tile, A.S.T.M. Load-Bearing End or Side Construction				
Two cells in wall thickness, unplastered			6	
Two cells in wall thickness, plastered			*5*	
Three cells in 8 in. or less thickness, unplastered	12			
Three cells in 8 in. or less thickness, plastered one side		8½		
Three cells in 8 in. or less thickness, plastered	9			
Combination of Brick and A.S.T.M. Load-Bearing Tile				
4 in. brick and 4 in. tile, plastered one tile side	9			
Hollow Concrete Block or Tile				
One cell in 8 in. or less thickness, unplastered	16	12	10	8–*6*
One cell in 8 in. or less thickness, plastered	13	11	9–*7*	*7*
Solid Concrete				
Reinforcement not less than 0.2% in each direction	6–*5*	*4*	*3*	*2*
Hollow Gypsum Blocks				
Unplastered	*6*	*5*	*4*	*3*
Plastered	*5*	*4*	*4*	*3*
Solid Gypsum or Portland Cement Plaster				
Incombustible studs with metal or wire lath				*2*
Same as above with neat wood fiber gypsum plaster			*2*	
Hollow Partition with Gypsum or Portland Cement Plaster				
Incombustible studs with metal or wire lath, ¾ in. plaster each side				*3*
Same as above with 1 in. plaster each side			*2–4½*	
Wood studs with metal or wire lath, firestopped, ¾ in. plaster each side				*5–3*
Same as above, 1 in. neat wood-fiber plaster each side			*5*	

Character of Occupancy. Building codes quite commonly call for the minimum thickness of walls of industrial buildings such as warehouses and factories to be greater than the minimum thickness of walls of large residence buildings such as hotels and apartment houses where the loads do not require the heavier walls. Since strength is not the controlling

factor, the only reason for this requirement seems to be the desire to secure greater stability for the industrial buildings. The Building Code Committee of the Department of Commerce[1] does not agree with this practice and makes the following statements:

> Heavier floor loads, where not exceeding the allowable unit stresses, increase the vertical components of the applied pressure and add to the stability of the walls against lateral forces thereby giving the industrial buildings an advantage as compared with the residential buildings.
>
> Within the economic height of buildings with brick bearing walls the industrial or commercial building is more apt to have a rigid interior framework than the residential building.

The smaller residential buildings, such as dwelling houses, are so different in construction and use that they require special regulations concerning minimum wall thicknesses. The 8-in. wall is used quite extensively in dwelling-house construction, because the walls are short, because they are supported at frequent intervals by interior partitions, and, since the walls are low, the consequences would not be serious if such walls should fall during a fire.

Functions of Wall. Where loads are not the controlling factor, fire walls are commonly required to be thicker than bearing walls of corresponding height, and non-bearing walls may usually be thinner than the corresponding bearing walls. A separation of at least 4 in. of solid masonry is required in fire walls and party walls between combustible members which enter such walls from opposite sides. Panel walls in buildings of skeleton construction may usually be made 8 in. or 12 in. thick for any of the common masonry materials. Partitions may be made much thinner than exterior walls.

Height of Wall. The minimum thickness permitted for any section of a wall depends upon the distance of that section from the top of the wall. This distance is sometimes measured in feet but more often in stories with a maximum limit set on the story height. Detailed information concerning the relation between the height and thickness of masonry walls is given in those articles that deal with each type of masonry.

Story Height. The unsupported height between floors is an important factor in the stability of walls, and for that reason this condition is restricted by all building codes. The story height permitted by various codes varies from 15 times the wall thickness to 20 times the wall thickness. This ratio may be larger for solid masonry walls than for walls constructed of hollow brick because weight is an important factor in stability and this ratio is usually larger for the lower stories than it is for the top story where the vertical loads which contribute

to the stability are small. When walls are dependent upon floors for their lateral support, provision must be made in the buildings to transfer the lateral forces resisted by all floors to the ground.

Special provisions are made to cover excessive story heights such as exist in theaters and auditoriums. The lateral support provided in a horizontal direction by the floors may also be provided by vertical buttresses or cross walls. When buttresses and floors are used together to provide lateral support, the minimum wall thickness required for a given story height may be reduced, according to some codes.

Buttresses may entirely replace the floors so far as lateral support is concerned. These factors are considered in the paragraph on the spacing of buttresses.

The unsupported length of isolated piers is usually limited to 10 times the least dimension.

Spacing Buttresses and Cross Walls. As explained under the paragraph on Story Heights, the minimum thickness for walls is dependent upon the degree of lateral support. Lateral support may be provided by the floors or by vertical elements such as buttresses and cross walls. The Building Code Committee of the Department of Commerce[1] recommends that the minimum wall thickness shall be a specified fraction of the story height or of the spacing of cross walls or properly designed buttresses, the smaller of the two values being used.

If floors and buttresses are used together to provide lateral support, some codes permit the maximum wall thickness, as determined by the height of wall or the story height, to be reduced by $\frac{1}{2}$ the projection of buttresses. The requirements for the width of buttress vary from $\frac{1}{8}$ to $\frac{1}{12}$ the clear distance between buttresses and the requirements for the clear distance between buttresses vary from 18 to 24 times the wall thickness. The minimum thickness for the wall between buttresses is commonly 12 in.

Some codes require that the same amount of material be used for walls with buttresses as required for plain walls. Where buttresses are used, they are required to be so placed that the principal girders and trusses will bear on them.

If the length between cross walls or buttresses is greater than 50 to 100 ft., depending upon its thickness and upon the code under consideration, an increase of 4 in. in the minimum wall thickness is frequently required. This requirement is to reduce the tendency of long walls to buckle and fall from the expansion produced by heat in times of fire.

Window and Door Openings, Chases, Recesses, etc. The Building Code Committee of the Department of Commerce[1] makes the follow-

ing statement concerning the effect of openings on the prescribed minimum wall thickness:

It is customary in about one-third of existing codes to require that bearing walls be increased 4 in. in thickness when a certain percentage of the wall section (varying in different codes 25 to 55 per cent) in any horizontal plane is removed for openings. This practice is a survival from the period when maximum masonry stresses were not prescribed and the increase of thickness was required to take care of possible excessive stresses in walls thus reduced in section. If the compressive stresses in masonry walls are kept within the prescribed limits and if serious eccentricity in loading of piers and short wall sections is avoided, it is believed unnecessary to require increase in wall thickness on account of openings.

It is common practice to leave vertical and horizontal grooves on the inside of masonry walls to accommodate steam and water pipes, electrical conduit, etc. These grooves are often of considerable size. Such grooves are called *chases*. They are covered over by the plaster surface so that the pipes are concealed. It is also common practice to provide depressions in the inside of masonry walls to permit radiators, switch boxes, etc., to be set back in the walls so that their faces will be flush with the wall face. Such depressions are called *recesses*. Building codes place restrictions on chases and recesses in order to avoid undue weakening of walls.

Span of Beams. Building codes commonly require that, when the clear span of a floor is greater than 26 ft., the thickness of bearing walls supporting the floor shall be increased 4 in. over that normally required for each 13 ft. or fraction thereof that the span exceeds 26 ft. The Building Code Committee does not agree with this requirement. It states that:

This practice is believed to date back to the era when working stresses for masonry were not limited directly, but by controlling the live loads likely to come upon the walls. Where masonry stresses are kept within the prescribed limits, the spans of floor beams should not affect the required thickness of masonry walls.

Bond. Walls that are not constructed of the same material throughout their thickness but that have a facing of stone or special brick must meet certain requirements concerning the bond or tie between the face and the backing in order that the face material may be included as a part of the required wall thickness. These requirements depend upon the materials used and are discussed in the articles which follow.

Materials. Many different materials are used for constructing walls and partitions, the most common being brick, stone, hollow clay tile, and concrete, which are classed as fireproof materials; and wood siding, stucco, or plaster supported by wood studs, which are classed as non-fireproof materials.

Each of these will be considered in subsequent articles.

ARTICLE 25. BRICK MASONRY

Brick for structural purposes may be made of clay or shale; portland cement and sand; lime and sand.

Clay-brick exterior walls are used in all classes of building construction from small dwelling houses to the finest public buildings. Concrete or cement brick and sand-lime brick are used to a limited extent.

Manufacture, Properties, and Classes of Brick

Manufacture. Clay and shale brick are made by three different processes: The soft-mud process, the stiff-mud process, and the dry process. In all these processes, the brick are molded to the desired shape, are dried, and are burned in kilns. The chief difference in the processes is in the method of molding.

In the *soft-mud process,* the clay is mixed with water and worked into a uniform plastic mass. Brick are shaped by pressing this material into molds by hand or machinery. To keep the brick from sticking to the molds, the molds may be wet with water or they may be sanded. If the molds are wet, the method is known as *slop-molding* and the brick are called *water-struck brick.* If the molds are sanded, the method is known as *sand-molding* and the brick are called *sand-struck brick.*

In the *stiff-mud process,* just enough water is used with the clay to produce a mixture which may be forced through a die, forming a ribbon whose cross-section equals that of the flat side or bed of a brick or the end. The brick are cut from this ribbon by tightly stretched wires, forming *wire-cut brick.* If the beds are cut by the wires the brick are called *side-cut,* but if the ends are cut they are called *end-cut.*

In the *dry-pressed process,* the clay of dry consistency is pressed into gang molds with plungers, exerting a heavy pressure. This process produces the most accurately formed brick.

Brick which are pressed in oversize molds, dried, and then repressed to the correct size are called *repressed brick.* Such brick are accurately formed and strong. Stiff-mud brick are frequently repressed.

Clay and shale brick are very extensively used in all parts of the country. By selecting clays and shales and introducing certain oxides, face brick of various colors are produced.

Concrete or cement brick are usually made by pressing a rather dry mixture of portland cement, sand, and water into gang molds. On account of the dry mixture used, the molds can be immediately removed without waiting for the cement to set. The brick are placed in an atmosphere of steam or are sprayed with water while the cement is setting. This class of brick should be called *concrete brick* rather than cement brick.

The ordinary concrete brick is a dead cement color which is not suitable for face brick. Different finishes are made on the exposed face by putting aggregates or colored cements on one side of the mold before pressing and backing this up with an ordinary mixture.

Concrete brick are quite widely used in some parts of the country, particularly where suitable clay for brick making is scarce.

Sand-lime brick are made of a mixture of sand and hydrated lime pressed into shape in molds and cured in an atmosphere of steam which causes chemical action to take place between the sand and lime thereby cementing the materials together.

Size, Shape, and Unit of Measure. The standard size for American face brick is $2\frac{1}{4}$ by $3\frac{3}{4}$ by 8 in. but brick made in the same size molds will differ in size on account of the variation in the amount of shrinkage of different clays in burning. Roman brick which are used to a limited extent are $1\frac{1}{2}$ by 4 by 12 in., Norman brick $2\frac{3}{4}$ by 4 by 12 in., and English brick 3 by $4\frac{1}{2}$ by 9 in. Various sizes of brick are shown in Fig. 65*a*.

Special shapes are available for use in forming a finish around openings or for moldings. These special shapes are not commonly used for ordinary brickwork but are available in face brick and in the glazed and enameled clay brick described later. The most common forms are the *bull-nose* and *double bull-nose*, shown in Fig. 65*b*, for use where a rounded corner is desired. Other shapes are the *internal bull-nose*, the *external octagon*, the *internal octagon*, the *cove header*, and the *cove stretcher*, as shown in Fig. 65*b*. *Hollow brick*, as shown in Fig. 65*b*, are made for use as face brick or backing brick to reduce the weight of a wall and to get the advantage of the air space in heat insulation and checking the passage of moisture through the wall.

The six surfaces of a brick are sometimes called the *face*, the *side*, the *end*, the *cull*, and the *beds* as shown in Fig. 65*d*.

Brick may be cut into pieces of various shapes, the more common of which are shown in Fig. 65*e* and are known by the following names: *half* or *bat*, *three-quarter*, *closer*, *king closer*, *queen closer*, and *split*. They are used to fill in the spaces at the corners and other places which the full brick will not fit.

Brick are always sold by the thousand.

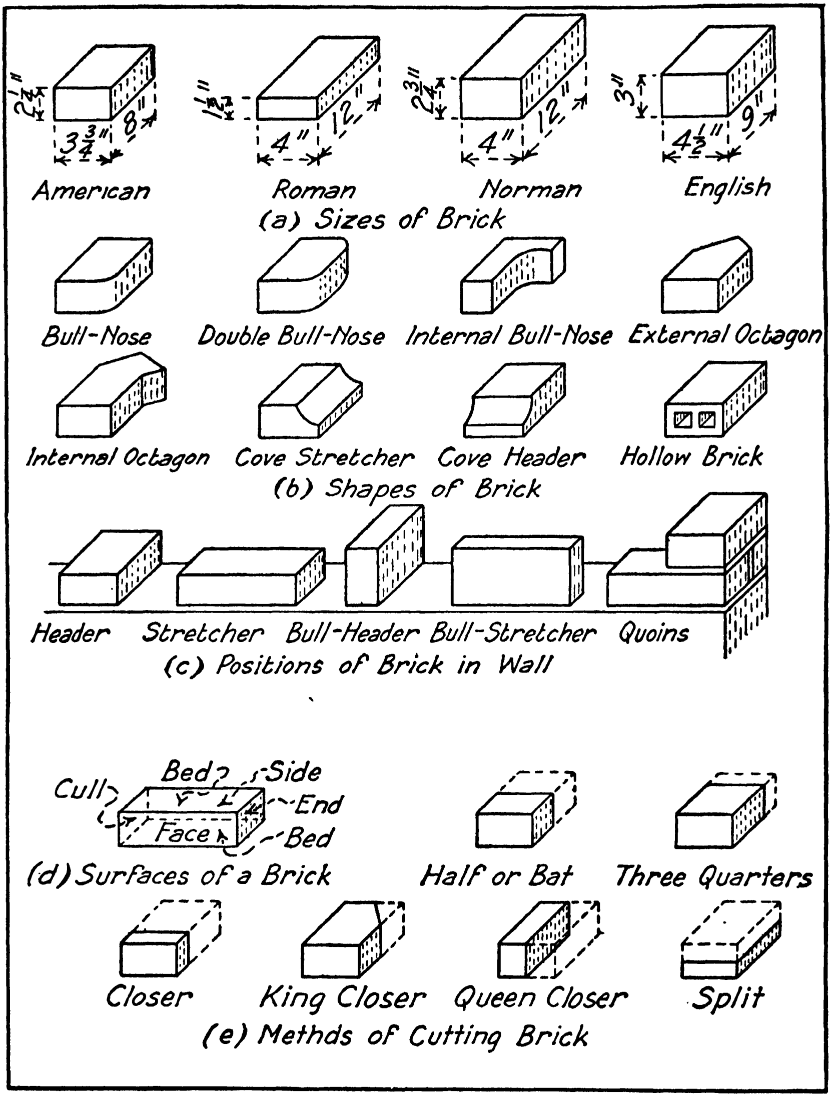


FIG. 65. Brick Types and Dimensions

Hardness of Clay Brick. The durability of a clay and shale brick depends largely upon the degree of burning it has received in the kilns. When removed from a kiln, brick are sorted according to their hardness which depends upon the degree of burning. The brick which

immediately surround the fire are usually overburned and are badly warped and discolored. These are known as *arch* or *clinker brick* and are suitable for use in foundations or similar places, for they are very durable but unattractive. The brick which have received the right amount of burning are known as *hard* or *well-burned brick* and are suitable for general use. The brick which are the most remote from the fire are underburned and are known as *soft brick*. These brick are weak and will not resist the action of the weather. They are suitable for use only as backing brick, where moisture is not encountered and where strength is not an important factor. The terms *salmon*, *pale*, and *light* are often applied to soft red brick.

Color of Clay Brick. Common brick used where appearance is not a factor are usually made of clay which burns red, but in some cases common brick are white or cream-colored. Very attractive walls are built of common brick by careful selection of the brick, the type of joint, and the bond.

Brick used on exposed faces of walls where the appearance is a factor are known as *face brick*. By mixing clays and introducing certain oxides a great variety of colors may be secured. The most common colors are various shades of red, brown, and gray. Many effects are produced by the fire markings in burning.

Surface Finish of Clay Brick. The exposed face of brick may be smooth or may be roughened by *wire cutting* or by *combing*, as in *tapestry brick*.

Glazed brick are smooth-faced brick of special composition which will permit a glaze being formed on the face exposed to the gases in the furnace produced by throwing salt into the fires of the kiln. This is called a *salt glaze* and does not require an additional burning. The common colors of salt glaze are gray, brown, and green. Salt-glazed brick are impervious, smooth, and easily cleaned. They are suitable for interior as well as exterior use, the whole wall surface being covered or simply the wainscoting. Glazed and facing hollow clay tile are made for use with corresponding brick as described in Art. 27.

Enameled brick are made by coating the surface of smooth unburned clay brick of special composition with a wash which gives an enameled surface when the brick are burned. The common colors are white, green, and brown. The surface may have a bright, medium, or dull finish. Enameled brick are impervious, smooth, and easily cleaned. They possess these qualities to a higher degree than salt-glazed brick and are more expensive. Enameled brick are suitable for interior and exterior use. They are particularly desirable for swimming pools,

hotel kitchens, and in other positions where wall tile might also be used.

Fire-flash or *fire-mark* brick are those brick which have acquired a surface marking by exposure to the fires of a kiln.

Face, Backing, and Common Brick. Brick are divided into *face brick* and *backing brick*, according to the part of the wall in which they are placed. Face brick are those which are used in the exposed face of a wall whereas backing brick are those which are used in the back of the wall. Face brick are of higher quality, greater durability, and better appearance than backing brick. Backing brick may often come from the same kiln as the face brick but they are of inferior quality due to underburning or overburning.

Brick are also divided into *face brick* and *common brick*. In this classification, brick which are made especially for facing purposes by selecting the clays to produce the desired color or by special surface treatment are called face brick, whereas brick which are made from the natural clay and do not have a special surface treatment are called common brick. Selected common brick are frequently used for face brick. They frequently have attractive fire marks.

Quality of Brick. The quality of brick is determined by its strength, durability, and appearance.

Specifications for building brick made from clay or shale have been prepared by the American Society for Testing Materials. These specifications divide such brick into three grades, depending on exposure conditions, as follows:

Grade SW. Brick intended for use where exposed to temperatures below freezing in the presence of moisture, such as those used in foundation courses and parapets in the northeastern quarter of this country.

Grade MW. Brick intended for use where exposed to temperatures below freezing but unlikely to be saturated with water, such as face brick or brick intended for structures located in regions characterized by less severe frost action or drier climate than found in the northeastern quarter of this country.

Grade NW. Brick intended for use as back-up or interior masonry; or, if exposed, for use where no frost action occurs; or, if frost action occurs, where the annual precipation is less than 15 in.

The grading is based on the compressive strength, on the amount of water absorbed under standardized conditions, and on the performance in alternate freezing and thawing tests.

Brick Masonry

Brick masonry consists of brick built up to form walls or other structural elements. In order to secure an even bed for the brick, to hold brick in position, to make a tight wall, and to improve the appear-

ance, mortar is used between the brick and forms the *joints*. The brick are held together to act as a unit by arranging them so that they lap over each other and break the vertical joints. The various arrangements which are used are called *bonds* and affect the appearance of the masonry. Brick may be arranged to carry out designs or *patterns* which have no bonding effect.

Headers, Stretchers, etc. Brick may be placed in various positions in a wall. If they are laid flat with the end exposed they are called *headers*, and if laid flat with long side exposed they are called *stretchers*. Half-brick which are used to give the appearance of headers but which do not project into the backing are called *false headers*. For sills, belt courses, etc., brick may be placed on edge with the end exposed and are called *bull headers*. Occasionally they are laid on edge with the flat side exposed forming *bull stretchers*. Belt courses and flat arches may be formed of brick set on end with the narrow side exposed. Such brick are called *soldiers*. *Quoins* are brick placed at corners with one end and one side exposed. These classes of brick are illustrated in Fig. 65.

Bonds. The arrangement of brick in a wall to tie the parts together by lapping the brick in various ways is called the *bond*.

In *running* or *stretcher bond* the face brick are all stretchers, as shown in Fig. 66*a*, the face brick being tied to the backing by metal ties placed in the horizontal joints, by using clipped or secret bond as described later, or by splitting the face brick of every sixth course in half lengthwise so that a continuous row of headers may project halfway through the course and into the backing.

In *common* or *American bond* every sixth course of stretcher bond is made a header course, as shown in Fig. 66*b*. This gives a much stronger wall than that secured with metal ties.

English bond consists of alternate courses of headers and stretchers, the vertical joints in the header courses all coming over each other and the vertical joints in the stretcher courses also being in line. The vertical joints in the stretcher courses bisect alternate brick in the header courses, as shown in Fig. 66*c*.

English cross bond, Dutch bond, or *cross bond* is similar to English bond, but the alternate courses of stretchers break joints, as shown in Fig. 66*d*. This wall is seen to be built up of interlocking crosses consisting of two headers and a stretcher, one of which is shown black in the figure to illustrate the cross.

In *Flemish bond* each course consists of alternate headers and stretchers, the alternate headers of each course being centered over the stretchers in the course below, as shown in Fig. 66*e*.

Header bond consists entirely of headers laid to break joints. An entire wall would not usually be laid in header bond but certain areas

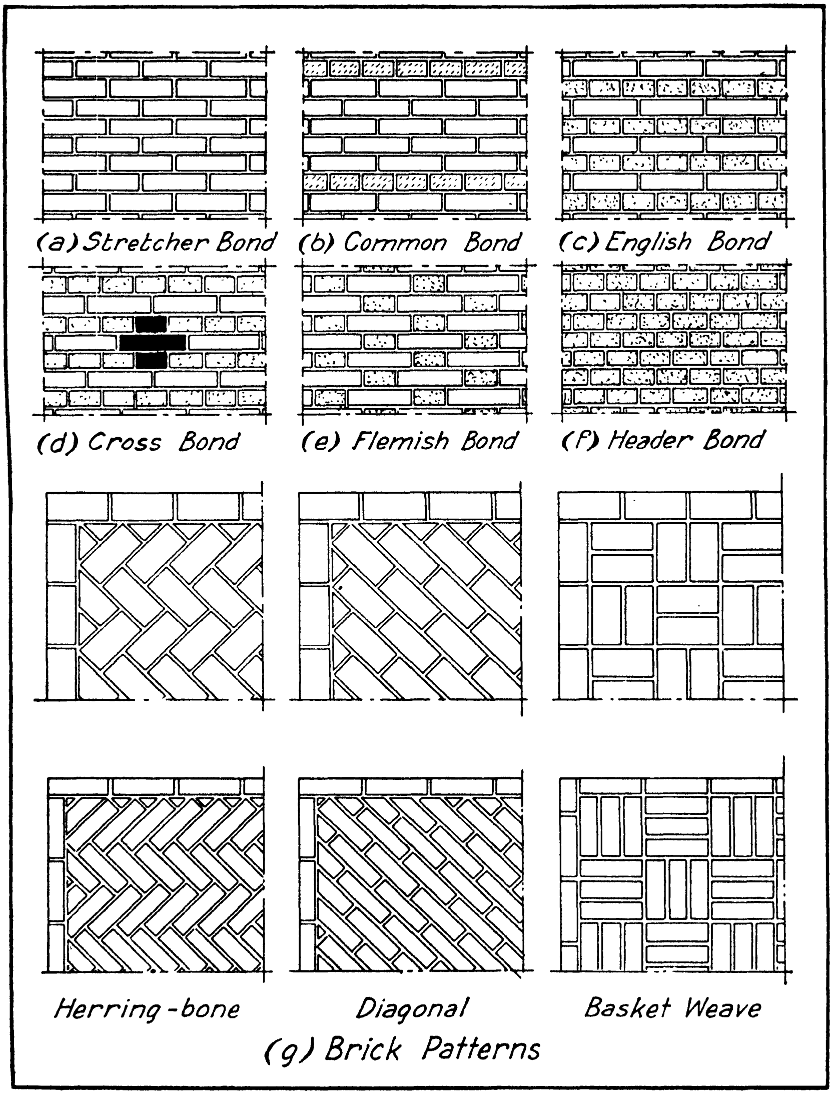


FIG. 66. Brick Bonds and Patterns

of a wall may be laid in header bond for decorative effect. See Fig. 66*f*. A large part of the headers may be false headers.

In *clipped* or *secret bond* face brick are laid in running bond, but the inside corners of the brick in every sixth row are clipped to permit a tie to be made with backing by headers laid diagonally. This bond offers very little resistance to the separation of the face and backing, so it is frequently desirable to use metal wall ties in addition to the clipped bond. These ties should be used on every brick of the course halfway between the diagonal header course. This construction gives a stronger wall than the use of wall ties only but is not as satisfactory as the other bonds which have been described.

The metal *wall ties* may be galvanized iron strips not thinner than No. 26 U. S. Standard Gage 1 in. wide and about 6 in. long, corrugated to give better bond; or ties may be made of heavy galvanized wire not smaller than No. 12 B. & S. Gage bent into the shape of the letter S.

Patterns. A great variety of patterns may be worked out by the use of headers and stretchers arranged in various ways. These may be emphasized by using headers differing slightly in color from the stretchers. Other patterns are secured by arranging face brick in diagonal and vertical positions. The most common patterns of these are the *herringbone*, the *diagonal*, and the *basket-weave patterns* shown in Fig. 66*g*.

Skintled Brickwork. Skintled brickwork consists of setting the face brick as in running bond but so that they are out of line with the face of the wall. The corners may project or be recessed from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. or more. The mortar which squeezes out of the joint may be allowed to remain. This type of brickwork is liable to leak and collect dirt.

Joints. The mortar layers between brick are called *joints*. The joints used in brick masonry may be as thin as $\frac{1}{8}$ in. for enameled or glazed brick walls where a surface which is easily cleaned is desired, or they may be as thick as $\frac{3}{4}$ in. to secure certain architectural effects, the most common thickness being from $\frac{3}{8}$ in. to $\frac{1}{2}$ in.

The joints in brickwork are usually made by the following operations all of which are performed with a trowel:

1. Spreading enough mortar to form the horizontal joint for three or four brick.

2. Cutting off the mortar which projects over the edge to keep it from running down over the face of the wall.

3. Bedding the brick one at a time by tapping with the trowel until they are in position.

4. Cutting off the mortar which has been forced over the edge by the bedding process and buttering the end of the brick to form the next vertical joint. This forms a rough-cut joint.

5. Jointing or finishing the exposed surface of the joints. The various types of joints are shown in Fig. 67. This method does not fill the vertical joints.

Push or *shove* joints are formed by placing a brick on a heavy bed of mortar and pushing or shoving it into position against a brick in the same course which has already been placed, in such a way as entirely to fill the vertical joint between the two with mortar. Walls constructed in this manner are stronger and more water-tight than walls constructed in the usual way.

Buttered joints are formed by holding the brick bottom up and buttering mortar on the bottom around the four edges of the bed and on the vertical edge which will come in contact with the last brick laid. The

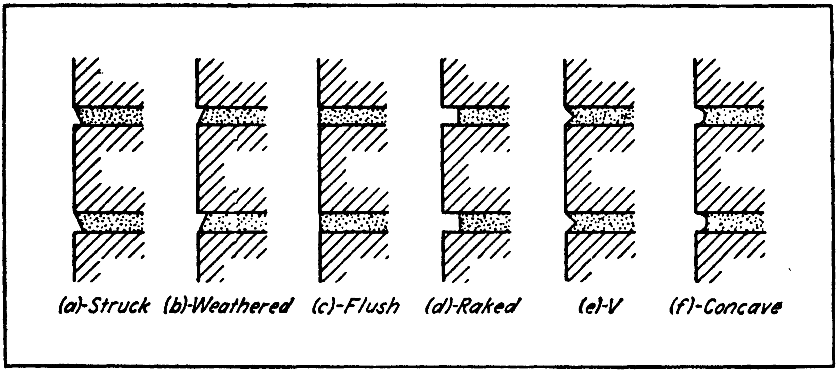


FIG. 67. Types of Joints

brick is then placed and tapped with the handle of the trowel to set it accurately. Narrow joints in enameled or glazed brickwork are commonly formed in this way. At one time, face brick were set with buttered joints $\frac{1}{8}$ in. wide but this practice has been practically discontinued. With buttered joints, the mortar is around the edges of the brick but not under the central part.

The exposed face of mortar joints may be finished in various ways. This finish is always formed at the time the brick are laid and not afterwards as in pointing stone work.

The *struck joint,* shown in Fig. 67*a,* is the most common type used when a finished joint is required. It is likely to produce leaky walls.

The *weather joint,* shown in Fig. 67*b,* is similar to the struck joint but slopes in such a way that it is more effective in shedding water. The weather joint is more difficult to form than the struck joint and so is rarely used, but is more water-tight.

In the *flush joint*, shown in Fig. 67*c*, the mortar is cut off flush with the face of the brick. This type of joint is common for unexposed interior surfaces and is also used for face brick.

The *plain* or *rough-cut joint* is similar to the flush joint but is not made as carefully. It is the cheapest and easiest joint to form and is used where the appearance is not a factor.

The *raked joint*, shown in Fig. 67*d*, is formed by raking out the mortar to the depth of about ½ in.

The *stripped joint*, similar to the raked joint, is sometimes formed by placing wood strips in the joints as the brick are being laid. These strips insure a joint of uniform thickness. They may be removed as soon as the mortar has set slightly.

The *V joint*, shown in Fig. 67*e*, is made with a special tool which is run along the joint.

The *concave joint*, shown in Fig. 67*f*, is made with a special tool which is run along the joint.

The best joint, from the point of view of water-tightness and cost, is the concave joint. The struck joint although easily made is not water-tight and is suitable for interior walls only. Raked and stripped joints are suitable only for interior masonry. They are relatively expensive and are not water-tight. All joints in exterior walls, including the vertical joints and the interior joints, should be entirely filled with mortar to reduce moisture penetration. The outside face of the joints should be made smooth and dense by exerting considerable pressure on the tool with which they are formed.

The brickwork for all party walls, fire walls, and bearing walls that carry heavy loads should be laid solid with all joints filled with mortar.

Mortar. The mortar used for brickwork above ground is usually a lime mortar consisting of 1 part by volume of slaked lime (lime putty) or dry hydrated lime and not more than 4 parts by volume of sand mixed with the proper amount of water to make it workable.

Cement mortar consists of 1 part portland cement to not more than 3 parts sand proportioned by volume. In order to increase the workability and possibly the water-tightness, not more than 15 per cent of the cement by volume may be replaced by an equal volume of dry hydrated lime. The lime and cement should be thoroughly mixed before the addition of water. The mortar must be used immediately after the water is added. Cement mortar is used for laying brick in foundation walls where they will be subjected to moisture, for bearing walls where the strength is of importance, and for fire walls where resistance to fire is of value.

Cement-lime mortar is made of 1 part portland cement, 1 part slaked or dry hydrated lime, and not more than 6 parts of sand, proportioned by volume. This mortar is stronger and more durable than lime mortar, but is excelled by cement mortar.

Mortar is sometimes made of 1 part natural cement to 3 parts sand, proportioned by volume. This makes a better mortar than lime mortar but is inferior to portland cement mortar.

The sand used in making mortar should be clean, but sharp sand is not necessary. Coarse sand is better than fine sand, but a sand graded from fine to coarse is better than either.

Mortar of almost any color may be produced by mixing mineral mortar colors with the mortar. Mortar colors may be in the form of a paste or a powder. The common colors are red, brown, chocolate, and black but many other colors are available or can be secured by mixing colors.

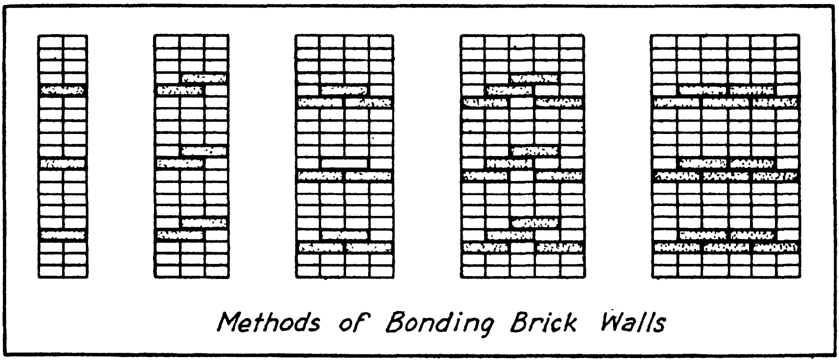


FIG. 68. Methods of Bonding Brick Walls

Wetting Brick before Laying. All brick should be thoroughly wet just before being laid, except in freezing weather, when they should be laid dry. The bricks are wet to keep them from soaking the water out of the mortar where it is necessary for proper setting, to secure a better bond between the brick and mortar and to wash off the dust on the brick. In freezing weather, brick which have been wet may be coated with a thin film of ice which will keep the mortar from penetrating into the brick and securing a hold.

Bond Required. Every sixth course on both sides of a wall should be a header course, except where walls are faced with brick in Flemish bond and English bond, in which case the headers of every fourth course should be full brick-bonded into the backing. The remaining headers may be half-brick called false headers. Where run-

ning bond is used, it should be bonded into the backing by using clipped bond combined with metal wall ties, as described in the paragraph on clipped bond, or by using split stretchers, as described in the paragraph on running bond.

In walls more than 12 in. thick the inner joints of header courses should be covered with another header course which shall break joints with the course below.

Desirable methods of bonding brick walls of various thickness and types are shown in Fig. 68.[1]

Face brick should be laid at the same time as the backing. The walls of each story should be built up the full thickness to the top of the beams or joists above.

Anchorage at Wall Intersections. All walls should be securely anchored and bonded at points where they intersect. Where such walls are not built at the same time, the perpendicular joint should be regularly toothed with 4-in. offsets, and the joint should be provided with anchors of not less than 2-in. by $\frac{3}{8}$-in. metal, with bent-up ends or cross pins to form anchorage; such anchors to be not less than 3 ft. long, extending 18 in. on each side of the joint and spaced not more than 3 ft. apart in height.[1]

Hollow Walls. Brick walls may be made hollow so that the open space will not permit rain water to pass through completely. Water which penetrates the outer layer should be conducted out again by flashing. There are three ways in which hollow walls are constructed, i.e., the *rolock wall*, consisting of bull stretchers and bull headers, as shown in Fig. 69*a*; the *bonded hollow wall*, shown in Fig. 69*b*, in which the layer of face brick is separated from the backing by an air space of about 2 in. through which the headers pass to bond the face brick to the backing; and the *cavity wall*, shown in Fig. 69*c*, which replaces the headers with metal ties.

The rolock wall is recommended for small dwellings where the height does not exceed 20 ft.[1] The hollow wall with headers is not as effectively bonded as the solid wall with the same number of layers. The headers in the rolock and bonded hollow walls may collect water and cause moisture penetration.

In the cavity wall, the metal ties, if properly made, do not facilitate moisture penetration. They are effective in keeping the two layers or withes from separating but no part of a load applied to the inner layer can be transmitted to the outer layer by the ties. Some building codes permit only the thickness of the loaded part of the wall to be considered in determining the effective thickness in such cases, and this effective thickness is required to be 8 in. or over, depending on con-

ditions. On this basis, the two-withe cavity wall would not be permitted but the New York City Building Code requirements given at the end of this article are in accord with recent trends.[18] The ties commonly recommended for cavity walls are Z-shaped, round steel rods at least ¼ in. in diameter, galvanized, cement-coated by a special process, or at least painted to protect against corrosion; but copper or bronze ties would be more dependable. Ties are spaced not farther apart than 3 ft. horizontally and 16 in. vertically.[6,18] Secondary advantages of hollow walls are improved heat and sound insulation, elimination of

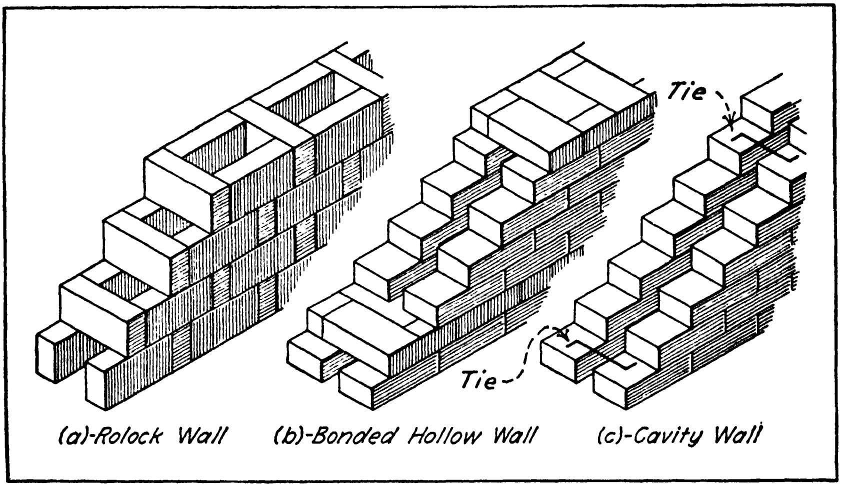


FIG. 69. Hollow Walls of Brick Masonry

furring, and, as with the rolock wall, a saving in material. Hollow walls of brick are not yet used to any extent in this country, but the cavity wall is extensively used in England and on the Continent.[7] They appear to have possibilities which deserve serious consideration because of their successful use abroad.

Stucco or Brick. Exterior walls of brick are frequently covered with stucco. In this case the surface brick should be rough hard-burned arch brick set in portland-cement mortar with joints not less than ⅜ in. thick, and with the mortar raked out for at least ½ in. from the face to give better bond between the stucco and brick. The surface of the brick should be brushed free from all dust, dirt, and loose particles, and should be wetted to such a degree that water will not be rapidly absorbed from the stucco, but not to such a degree that water will remain standing on the surface when the stucco is applied.

The composition and placing of the stucco are discussed in Art. 75.

Face Brick with Hollow Tile or Hollow Brick Backing. Face brick may be backed with hollow tile or with concrete blocks, as discussed in Art. 27. The facing should either be bonded to the backing with a row of headers every 16 in. or be attached to the backing with metal wall ties bedded in the mortar joints. Such ties should be spaced not farther apart than 1 ft. vertically and 2 ft. horizontally. When metal ties are used, the face brick can not be considered as a part of the backing in determining the required thickness of the wall, but if brick headers are used the face brick may be included.

Hollow tile backing may be used to decrease the weight, when panel or curtain walls are supported by a steel or reinforced-concrete frame, to increase the resistance to the passage of heat and moisture or to reduce the cost in cases where tile backing is cheaper than brick.

Hollow brick of standard brick size may be used to form the inside face of exterior walls, the air cells in the brick increasing the resistance of the wall to the passage of heat and moisture.

Brick Walls Faced with Stone. Brick may be used for backing walls which are faced with stone ashlar. The ashlar should not be less than 3¾ in. thick and each stone should be reasonably uniform in thickness but all stones need not be of the same thickness.

Each block of ashlar should be bonded into the backing, or securely anchored to the backing with metallic anchors, as described in Art. 26.

Frame Walls Veneered with Brick. This type of wall should be classed under frame construction and is discussed in Art. 37.

Trim Stone and Terra Cotta. Cut stone, as described in Art. 26, and architectural terra cotta, as described in Art. 28, are frequently used as a trim around window and door openings and for belt courses, copings, and cornices.

Cleaning. After the plasterer has completed his work, all surfaces of face brick should be thoroughly cleaned with a 5 per cent solution of muriatic acid. A stiff wire brush may be used to remove spots and stains. After cleaning, the surface should be carefully washed with water to remove all traces of acid.

Efflorescence. *Efflorescence* is a white deposit which frequently appears on the surface of masonry walls. It is caused by soluble salts, such as calcium and magnesium sulphates, contained in the brick or mortar being dissolved out by water's penetrating the brick or mortar and being deposited on the surface of the wall as the water evaporates.

In order for efflorescence to form, it is essential that both the water and the salts be present. Efflorescence may be minimized by the selection of materials which contain a minimum amount of the materials causing efflorescence and by keeping water out of the wall. This may

be accomplished, in part at least, by using water-repellent mortar and solidly filled joints; by capping walls with copings with tight joints and arranged to drip free of the wall or to drain toward the roof instead of toward the face of the wall, by effective flashing and calking, by waterproofing the inside of parapet walls, by providing drips for all sills, cornices, and projecting courses, by providing a waterproof layer on top of foundation walls, and by protecting the walls so that rain and water from melting snow can not enter the wall during construction. (See paragraphs on Moisture Penetration and on Flashing and Calking in Art. 24.)

Efflorescence can be removed by washing the wall with a weak solution of muriatic acid and water. Subsequent deposits may be prevented to a certain extent by applying a colorless waterproofing compound to the surface. This waterproofing must be renewed at intervals. The only satisfactory method of preventing efflorescence is in the selection of the materials and in proper design.

Colorless Waterproofing Materials. It may be desirable to treat the exposed surfaces of brick walls with colorless waterproofing materials to keep moisture from penetrating the walls and causing dampness, efflorescence, and disintegration. For a discussion of these materials see Art. 26.

Brick Arches. Brick arches are used over openings in brick walls, in brick arch floors as shown in Fig. 70*a* and in many other parts of buildings. Various forms of arches are discussed in Art. 24.

Brick arches may be constructed of one or more rows of brick on edge with the end exposed, as shown in Fig. 70*b*, forming a *rowlock arch;* with one or more rows of brick on end with the narrow edge exposed, as shown in Fig. 70*c*; with the courses forming the arch ring, bonded as shown in Fig. 70*d*; or with bonding courses at intervals, as shown in Fig. 70*e*.

The bricks may be adjusted to the curvature of the arch by making wedge-shaped mortar joints or by shaping the bricks to fit the spaces which they are to occupy and using joints of uniform thickness. Arches constructed of brick so shaped are called *gaged arches*, as shown in Fig. 70*d*, and *e*. This shaping is accomplished by laying the arch out on the floor and cutting and rubbing the bricks to the proper shape before the work of placing is started. Arches of other types than the rowlock will usually have to be gaged.

Two forms of *flat* or *jack arches* are shown in Fig. 70*f* and 70*g*. Such arches are often supported on concealed lintels in which case they are not true arches.

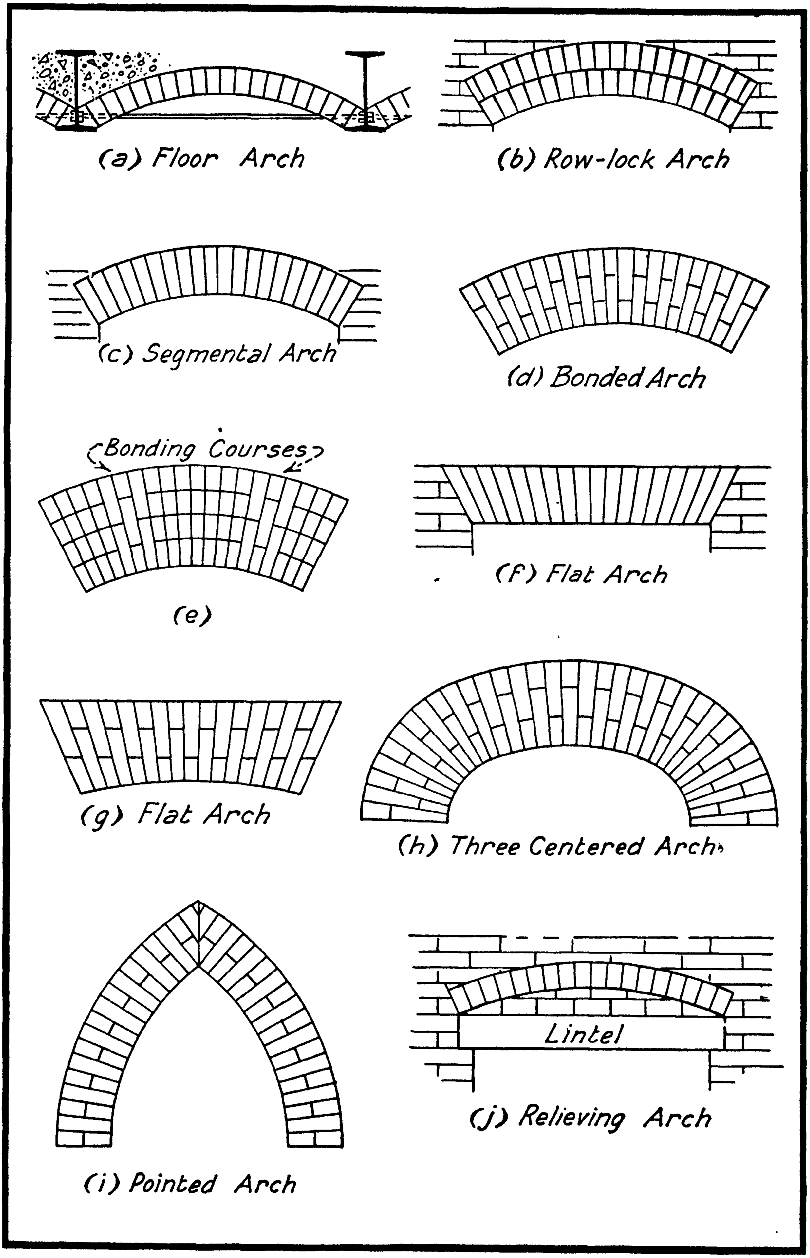


FIG. 70. Brick Arches

Brick arches are often constructed over lintels in the backing of brick or stone walls as shown in Fig. 70*j*. These arches are used to take the load from the lintels and are called *relieving* or *discharging arches.*

As previously mentioned, brick arches between steel beams may be used for floors as shown in Fig. 70*a*. Where a flat ceiling is desired a suspended ceiling of plaster or metal lath must be used.

The span of brick arches should not exceed 8 ft. The thickness should not be less than 4 in. for spans of 5 ft. or less, and 8 in. for spans exceeding 5 ft., and not exceeding 8 ft.; but for any span the arch should be proportioned to carry the imposed load. The rise should be at least 1 in. for each foot of span.

The arches should be composed of good, hard, common, or hollow brick, solidly bonded by breaking joints, and laid in cement mortar. Suitable skewbacks should be provided to receive the arch. The exposed part of the beams should be properly fireproofed. The remarks concerning tie-rods and cinder-concrete filling for tile arches also apply to brick arches.

The weight of brick arches is very great and their use is limited to floors carrying very heavy loads. They have practically gone out of use owing to the greater economy of other types of construction such as reinforced-concrete slabs.

Minimum Wall Thickness. The factors which affect the thickness of masonry walls are discussed in Art. 24.

The recommendations of the Building Code Committee of the Department of Commerce[1] for brick walls are as follows:

Wall thicknesses specified are nominal, referring to the minimum thickness obtainable with building units of standard size. It is common in some parts of the country to designate brick walls as 9, 13, and 17 in. in thickness, but with the standardization of brick and tile sizes now becoming general, it is more correct to express the dimensions as 8, 12, and 16 in.

Lateral Support. Solid brick walls shall be supported at right angles to the wall face at intervals not exceeding eighteen times the wall thickness in the top story or twenty times the wall thickness elsewhere. Such lateral support may be obtained by cross walls, piers, or buttresses, when the limiting distance is measured horizontally, or by floors when the limiting distance is measured vertically. Sufficient bonding or anchorage shall be provided between the wall and the supports to resist the assumed wind force, acting in an outward direction. Piers or buttresses relied upon for lateral support shall have sufficient strength and stability to transfer the wind force, acting in either direction, to the ground. When walls are dependent upon floors for their lateral support, provision shall be made in the building to transfer the lateral forces resisted by all floors to the ground.

Thickness of Exterior Walls Other than in Skeleton Construction. The thickness of solid brick bearing walls shall be sufficient at all points to keep the combined stresses due to live and dead loads for which the building is designed within the limits prescribed.

The minimum thickness for solid brick exterior bearing or party walls shall be 12 in. for the uppermost 35 ft. of their height, and shall be increased 4 in. for each successive 35 ft. or fraction thereof measured downward from the top of the wall; except that the top story exterior bearing wall of a building not exceeding three stories or 40 ft. in height, or the wall of a one-story commercial or industrial building may be 8 in. thick, provided that such 8-in. wall does not exceed 12 ft. unsupported height and that the roof beams are horizontal; and except that exterior solid brick bearing walls of one and two family dwellings may be 8 in. thick when not more than 30 ft. in height. When gable construction is used for such dwellings, an additional 5 ft. is permitted to the peak of the gable.

Where solid brick exterior bearing or party walls are stiffened at distances not greater than 12 ft. apart by cross walls, or by internal or external offsets or returns, at least 2 ft. deep, they may be 12 in. thick for the uppermost 70 ft., measured downward from the top of the wall, and shall be increased 4 in. in thickness for each successive 70 ft. or fraction thereof.

The minimum thickness of solid brick exterior nonbearing walls shall be 12 in. for the uppermost 70 ft. of their height, and shall be increased 4 in. for each successive 35 ft. or fraction thereof, measured downward from the top of the wall, except that the top-story wall of a building not exceeding three stories or 40 ft. in height, or the wall of a one-story commercial or industrial building may be 8 in. thick, provided that such 8-in. wall does not exceed 12 ft. unsupported height, and that the roof beams are horizontal; and except that solid brick non-bearing walls of one and two family dwellings may be 8 in. thick when not more than 30 ft. in height. When gable construction is used for such dwellings an additional 5 ft. is permitted to the peak of the gable.

Brick Fire Walls. Solid brick or fire walls shall be not less in thickness than required for exterior bearing walls of corresponding height, but not less than 12 in., except that solid brick fire walls for buildings of residential occupancy shall be not less than 8 in. thick for the uppermost 20 ft. of height and shall be at least 12 in. thick for the remaining lower portion. No 8-in. fire wall shall be broken into, subsequent to building, for the insertion of structural members.

Party walls which also function as fire walls shall conform to requirements for fire walls.

Fire-Division Walls. Fire-division walls of solid brick shall be not less than 8 in. thick.

Non-Bearing Partitions. For non-bearing partitions, materials meeting the ordinary accepted local standards for the purpose may be used.

Brick non-bearing partitions shall be not less than 3¾ in. thick for a height not exceeding 12 ft. between floors or floor beams and for a length not exceeding 20 ft. between vertical supports.

Panel and Inclosure Walls. Panel walls in buildings of skeleton construction shall be not less than 8 in. thick if of solid brick, hollow tile, concrete block or tile, plain concrete, or hollow walls of brick. Inclosure walls shall be not less than 8 in. thick nor less in thickness than one-twentieth the horizontal distance between anchors.

Foundation Walls. Foundation walls for solid-wall construction shall be of stone, solid brick, concrete (plain, rubble, or reinforced), or concrete block. Solid brick foundation walls and those of concrete block or coursed stone shall be not less in thickness than the walls immediately above them and in no case less than 12 in. thick, except that when the inclosure is not excavated, they may be 8 in. thick if included within the allowable height of 8-in. walls.

When the stresses due to earth pressure and superposed building load exceed the maximum working stress specified for brick masonry, and the additional stresses are not otherwise provided for, the wall thickness shall be increased to bring them within these limits.

It has been customary to require that foundation walls be made thicker than those immediately above them. The committee does not believe this necessary in all cases. A foundation wall acts both as a bearing wall and a retaining wall. As a bearing wall it has few or no openings compared to the walls above it, and its unit compressive stresses are usually lower. As a retaining wall it owes practically all its stability to the weight resting upon it, and except in very thin walls the addition of 4 in. of thickness increases its resistance to side thrust very little. Where analysis of the forces acting upon it discloses combined stresses greater than those allowed or where such forces may cause tension in the masonry, the thickness should be increased.

Foundation walls should be waterproofed with cement plaster, or by other effective means, and unless surrounded by sand or gravel, or otherwise naturally drained, should have open tile drains around the footings on the outside discharging into an outfall at a lower level.

All foundation walls shall extend below the level of frost action.

The requirements of the Building Code Committee for hollow walls are given in Art. 27.

Amendments, effective July 15, 1940, to the New York City "Building Code"[18] included special requirements for hollow walls of solid masonry units which are known as *cavity walls.* They permit 10-in. walls with two withes to be used for private dwellings two stories high with the wall extending into the attic if desired.

When hollow walls are built of two or more separated withes, they are required to be bonded together with units similar to those used in the wall so that the parts of the wall will act together under load or they must be tied together with approved non-corroding metal ties, one tie being required for every 4 sq. ft. of wall surface.

The outer withe is usually tied, and not bonded, to the inner withe. For this construction, the inner withe carries all the wall load except the

weight of the outer withe and should be so considered in computing the unit compressive stresses in the masonry. Usually these are well within allowable values.

If walls are constructed so that floor and roof loads are effectively transmitted to both withes by solid construction through the wall at the roof level and at each floor level, the thickness of both withes can be considered in computing the unit compressive stresses in the masonry.

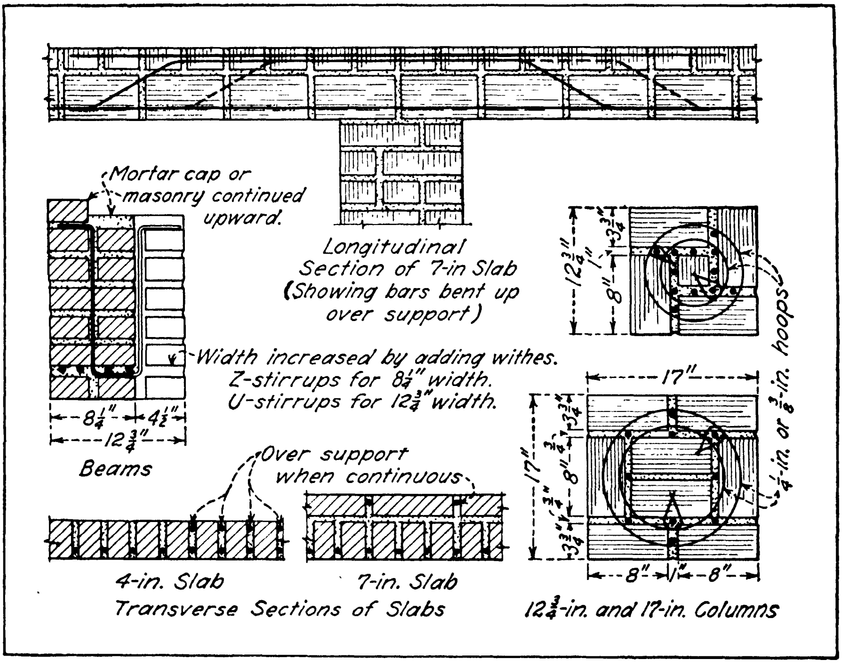


FIG. 71. Reinforced Brick Masonry

Reinforced Brick Masonry. Ordinary brick masonry has considerable compressive strength but practically no tensile strength. By inserting steel reinforcing bars in the mortar of certain joints in locations where tensile stresses would normally develop, brick masonry can be made to carry tensile stresses. Also, by inserting longitudinal reinforcement in the cores of brick piers and columns and ties or hoops in the horizontal joints, the compressive strength, the resistance to eccentric loads and the dependability of those members can be increased. Reinforced members may be incorporated in the remainder of the brick masonry and yet give no external evidence that they are reinforced.

Typical beam, slab, and column sections are illustrated in Fig. 71.

A complete treatment of the reinforced brick masonry is given in "Brick Engineering" by Harry C. Plummer and Leslie J. Reardon.[5]

ARTICLE 26. STONE MASONRY

Kinds of Building Stone and Their Uses. The composition, methods of formation, and properties of the various kinds of stone are considered in Art. 11. Stone masonry and cut-stone facings are extensively used in exterior and interior walls where appearance is an important factor; and *trim stone* in the form of belt courses, cornices, quoins, sills, jambs, and heads is widely used in exterior brick-masonry walls. Stone is also used on the interior of buildings for wainscoting, mantels, hearths, floor tile, steps, stairways, and in many other ways. Concrete has largely replaced stone masonry for foundation walls, but stone masonry is still used where a suitable stone can be obtained locally at low cost. Walks and terraces are commonly constructed of concrete, but stone is still used for these purposes to secure desired architectural effects.

Many stones which are satisfactory for interior use can not be used outside because of climatic conditions; and stones which are satisfactory for ordinary building purposes can not be used for steps, door sills, and floors because of their low resistance to abrasion. Stones which are durable, strong, and attractive in appearance may not be suitable for building purposes because of the labor required to work them into the desired shapes. Some stones which are not used for high-class masonry that requires the stones to be accurately shaped and carefully finished are satisfactory for the cruder forms of masonry. Stones soft enough to work readily are frequently not durable. Ornamental work, such as moldings and carvings, require a stone with even grain which is free from seams and other defects. Stones which are easily worked in any direction are called *free stones*. Delicate carvings require a stone of considerable strength to withstand injury. The architectural treatment of a building may demand stone of a certain color. Many other factors may enter into the selection of a stone for a specific purpose.

Granite quarries are located in several states, but most of the granite produced in this country is from quarries in eastern United States, from Maine to Georgia, and in Minnesota and Wisconsin. Vermont produces more granite than any other state. Granites are the hardest and most difficult to work of all building stones, but can be finished with a highly polished surface. They are available in a great variety of colors, including white, gray, pink, red, and green. Granite is used for masonry, steps, platforms, sills, trim stone, and as a thin facing or veneer over other masonry. It is also used in base courses and other locations requiring an extremely durable stone.

Marble deposits are rather widely distributed over this country. About 90 per cent of the marble produced comes from Tennessee, Vermont, and Georgia. Pure marble is white, but the other substances present produce a great variety of beautiful colors and color variations, characteristic of marble. The color patterns in marble, together with the stone's ability to take a high polish, make marble a valuable medium for decorative uses. Marble is used as a veneer for monumental buildings. In general it is used for exterior and interior decorative purposes, including wainscoting, panels, mantels, hearths, floor tile, and stairs.

Limestones are found in all parts of this country. Indiana leads all states in the quantity produced. As Indiana limestone or Bedford limestone, limestone from this state is shipped to all parts of the country. This stone varies in color from buff to gray, it is durable and easily worked in saws, planes, lathes, and other machines, and can be carved effectively and cheaply. Because of the low cost of working Indiana limestone, it can compete with local stones in most parts of the country despite transportation costs. Limestone is used for masonry, veneer over other masonry, trim stone, steps, sills, coping, flagstones, floor tile, and is used in many other ways on the exterior and interior of buildings. *Travertine* is a form of limestone that is used to a limited extent for ornamental purposes and floor tile. It contains small irregular cavities. This stone is imported from Italy, but travertine quarries are gradually being developed in Colorado, California, and Montana.

Sandstones are found in nearly every state, but Ohio produces more than half the sandstone used in this country. It is sold chiefly in the Middle West. The stones from Ohio are blue, gray, and buff in color. They have good working qualities and are durable. Sandstones are used for the same purposes as limestones. *Bluestone* and *brownstone* are names applied to sandstones because of their color, although some stones which resemble bluestone in their physical properties are called bluestone even though they are not blue. Bluestone is very strong and durable and splits readily into thin slabs. It is used for sidewalks, steps, flagging, and sills.

Detailed information concerning building stones can be obtained from "The Stone Industries" by Oliver Bowles,[9] which has been consulted in the preparation of this article.

Quarrying. Quarrying consists of separating rough blocks of stone from rock formations. In small quarries the work may be done entirely by hand tools with more or less assistance from explosives, but in the larger quarries machines are used. Explosives are used to a very

limited extent on account of the waste they cause. Their chief use is in removing the overburden to expose the solid stone.

The nature of the rock formation has an important bearing on the quarrying methods. The stratified sandstones and limestones have been deposited in layers as explained. The surfaces of contact of adjacent layers are called *beds*. In quarrying, advantage is taken of these beds which offer planes along which separation is easily accomplished. The beds may be so close together that the stone is only useful for *flagging* or they may be so far apart or so indistinct that they are of little assistance in quarrying; but the stone may be of greater value in spite of this fact, for the size of the stones is then not limited by the beds.

The unstratified rocks such as granite do not lie in separate layers but have a massive structure, and surfaces of separation have to be made by artificial means. Such rocks may split more easily in one direction than in another.

Both stratified and unstratified rock formations may be divided by *seams* running in any direction. The presence of these seams may be an advantage in quarrying or a disadvantage on account of the limit they place on the size and shape of the pieces removed. These seams may be very conspicuous and offer a distinct surface of separation; they may not be discovered until considerable work has been done on a stone; or they may even cause failure after a stone has been placed in a structure. *Streaks* may occur in stone without necessarily reducing its strength.

If a formation is badly broken up by beds and seams, the rock may be removed with crow bars, picks, and wedges; but *dimension stones* are difficult to secure under these conditions except in small sizes.

Building stone is removed from the quarry in rough blocks which are later cut into pieces of the desired size. In separating the rough blocks from the rock formation, the rock may be broken along a line by drilling a row of closely spaced holes by hand or machine along that line and splitting the rock between the holes by means of *plug and feathers.* The plug is a steel wedge and the feathers are wedges rounded on one side to fit the outline of the hole and flat on the other to form a surface over which a wedge is driven, as shown in Fig. 72*a*. Plug and feathers are placed in each hole and the plugs are gradually driven in with a hammer, driving each plug a little at a time and in succession. By continuing this operation, a force of sufficient intensity to split the rock is developed. In stratified stones the blocks are split along a plane perpendicular to the bed, which gives a natural surface of separation. In unstratified rocks, plug and feathers may be used along two planes

at right angles to each other. Plug and feathers are also known as *wedge and shims*.

The splitting is sometimes accomplished by wooden plugs driven in the holes and soaked with water. The water causes the plugs to expand and exert forces which split the rock.

Channeling machines are widely used for quarrying. These machines cut narrow channels along the face of the block to be cut out. These channels are cut vertically and may be as deep as 10 or 15 ft. The

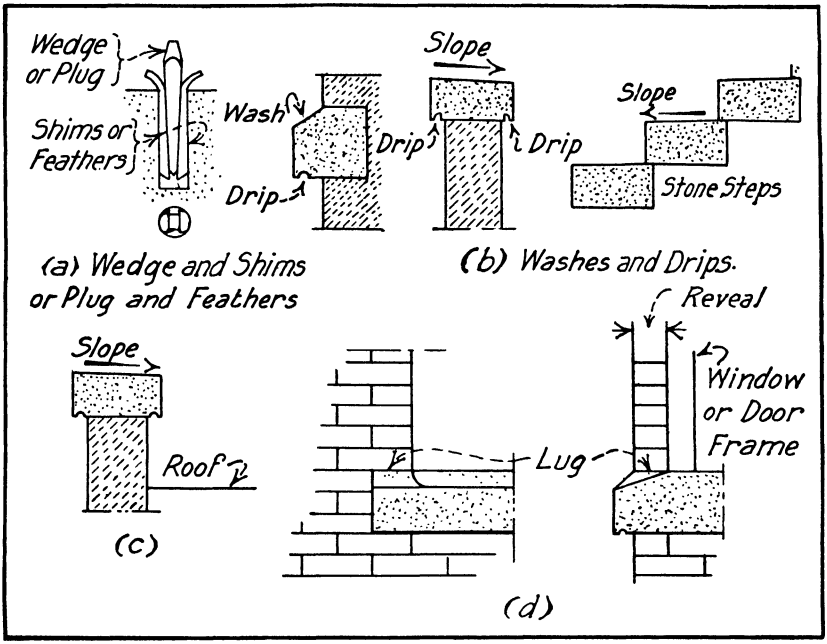


FIG. 72. Wedges and Shims, Washes and Drips

blocks are separated from the quarry ledge at a bedding plane, or they may be split along a horizontal plane by drilling holes and using wedges.

The plug-and-feathers method may be used on any kind of stone and is the method used in granite quarrying. The channeling method is not suitable for granite but is the method commonly used for quarrying limestone, marble, and sandstone. For the harder varieties of sandstone, however, the plug-and-feathers method is more suitable.

In many localities, stones found loose in the field are used for building purposes. These are called *field stones*. They may be used in the shape in which they are found or they may be split or shaped with

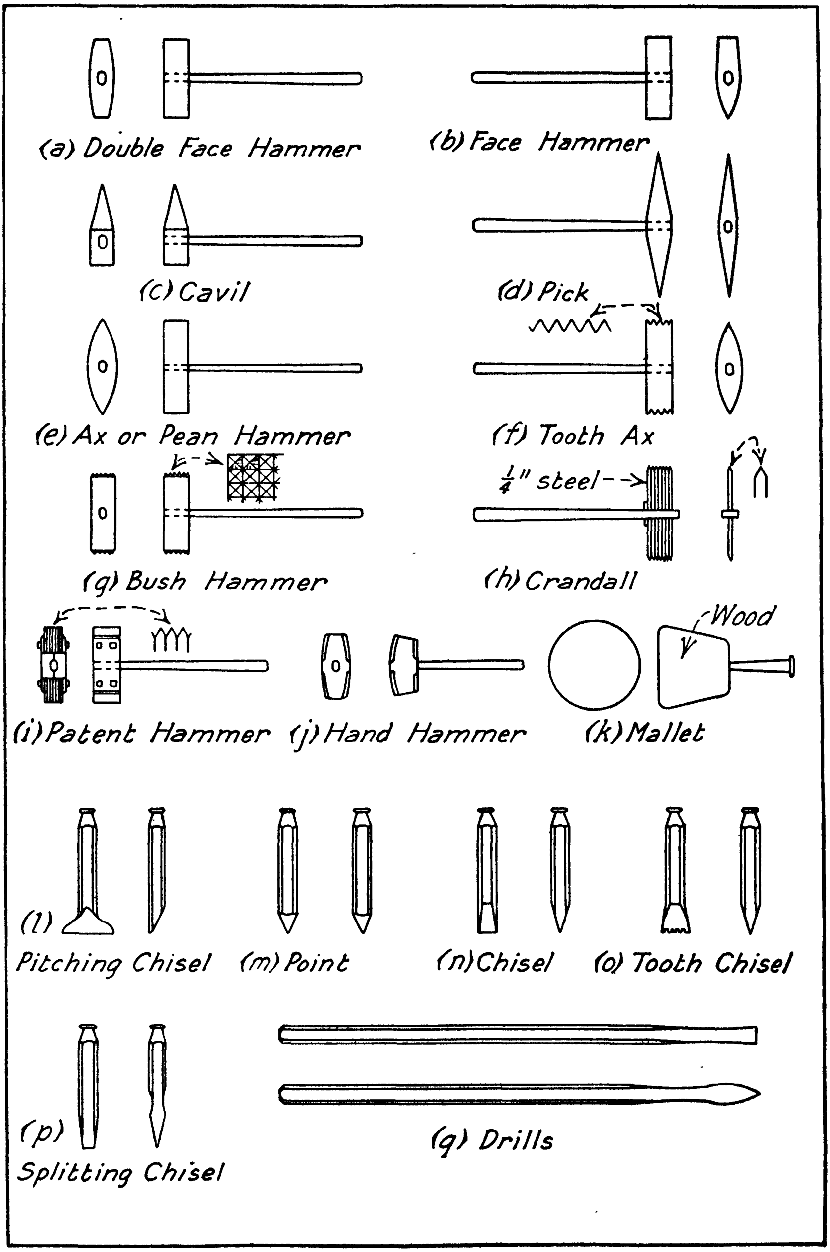


FIG. 73. Hand Tools Used in Stone Cutting and Finishing

the hammer. *Cobblestones,* which may be defined as large pebbles, are used in the same way.

Milling. The converting of quarried blocks of stone into the finished product is called *milling.* It includes such operations as *sawing* the blocks into slabs of the desired thickness with *gang saws* or *circular saws; planing* them to improve the surface finish or cut moldings on their surfaces; *turning* columns, balusters, etc., in *lathes; milling* recesses, patterns, and lettering on the faces of stones by means of a *milling machine; carving* the stone into various forms with hand tools, as shown in Fig. 73, or with pneumatic tools operated by hand, as shown in Fig. 74; and *finishing* the surface as described in the next paragraph. As stated by Bowles:[9]

> Some confusion exists in the application of the term *milling.* This word is used in a general way to cover all mill processes, such as sawing, planing, cutting, or carving, and is also applied to a particular type of equipment known as a milling machine. . . . *Cutting* is usually defined as straight-line work and *carving* as curved work.

Cut stone or dressed stone is the product of the stone mill. Stones of large size or special shape or any stone for which all dimensions are specified in advance, other than finished cut stone, are called *dimension stones.*

Surface Finish. There are various methods of finishing the exposed surface of building stone. The finish which is suitable for a given surface is governed by the kind of stone and the manner in which it is used and varies from the rough face formed in quarrying to the highly polished face often used on marbles and granites. The hand tools used in finishing are described in Vol. VI of the *Transactions of the American Society of Civil Engineers* and are shown in Fig. 73.

Tools used with pneumatic hammers are shown in Fig. 74.

A *quarry face* is a face which is on a stone when it comes from the quarry. It may be formed by the quarrying operations, or may be due to a natural seam and is then called a *seam face.* Quarries producing seam-face stone are traversed in all directions by natural seams forming relatively small blocks of stone of irregular shape and size. Seam faces are often highly colored by deposits from mineral-ladened waters which have penetrated into the seams.

A *split face* is formed by splitting a rock.

A *rock* or *pitch face* is one in which the four exposed edges forming the *arris* are clearly defined by a line beyond which the rock is cut away with a broad pitching chisel so that the edges are approximately straight and lie in a single vertical plane, as shown in Fig. 75*a*.

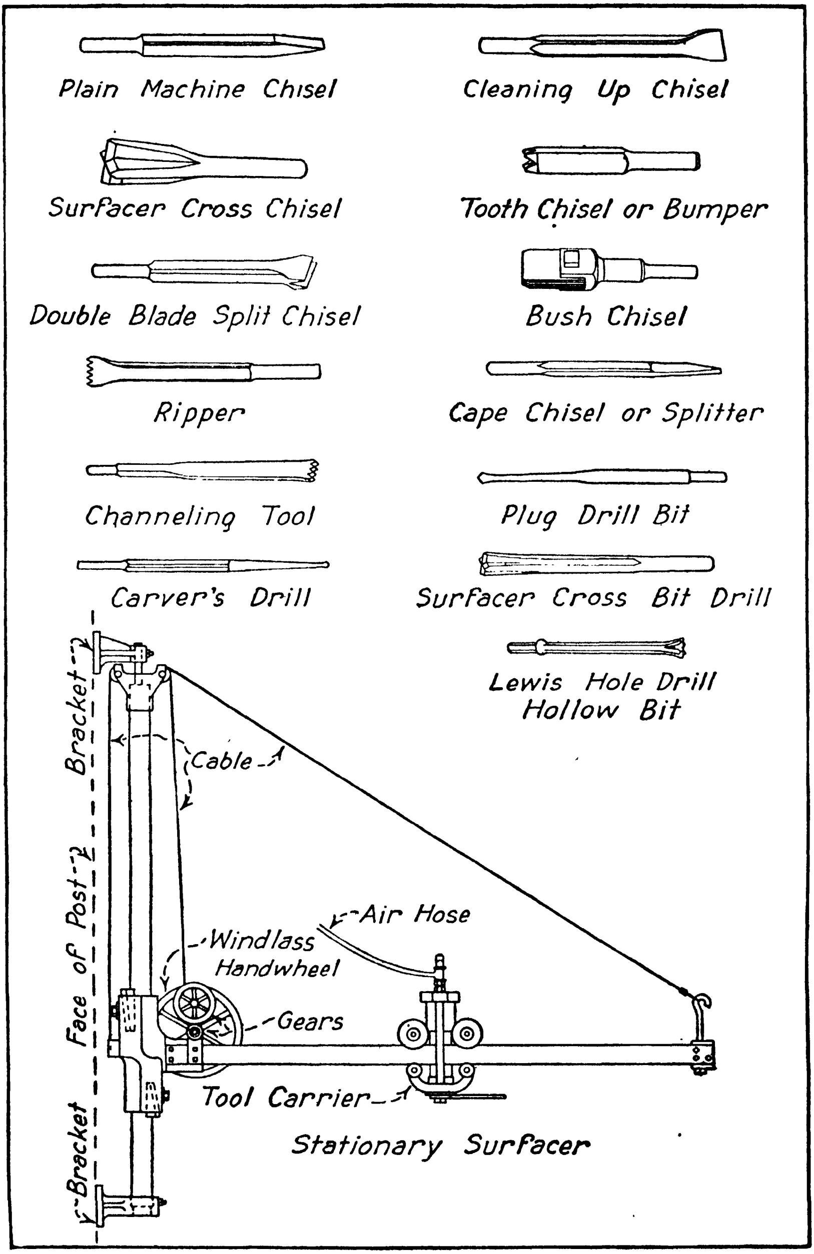


FIG. 74. Pneumatic Tools Used in Stone Cutting and Finishing

A *pointed finish* is one which has been dressed or finished with a pointing chisel until the general surface is flat but rough owing to the depressions left by the pointing chisel as shown in Fig. 75*b*. There are three grades of pointing, *fine, medium,* and *coarse* or *rough,* the grade depending upon the distance between the depressions. Pointing may be done by hand or by machine, the machine pointing generally being more regular. The crandall is used to produce a rough-textured surface somewhat resembling a pointed face where a much finer and more evenly tooled finish is desired than can be secured by pointing. See Fig. 75*i*. The tooth axe produces a coarser effect than that of the crandall, though similar.

A *hammered finish* is one which has been dressed or finished with hammers of various kinds until the general surface is flat but rough from the hammer marks. Surfaces which are to have a hammered face are first reduced to a fairly even surface by pointing. The *pean-hammered face,* as shown in Fig. 75*c,* is produced by finishing with a pean hammer, forming a surface with parallel lines, more or less regularly spaced. The *bush-hammered face,* shown in Fig. 75*d,* is produced by finishing with a bush hammer. The *patent bush hammer,* shown in Fig. 73, has a head with an opening about $\frac{7}{8}$ in. wide in which are bolted sets of 4, 6, or 8 cutting blades with parallel edges, giving 4, 6, or 8 cuts or bats in $\frac{7}{8}$ in. Surfaces which are to be finished with this hammer are first finished with a pean hammer operated in both directions to remove all traces of pointing. The *four-cut finish* is produced by following the pean hammer with a patent hammer with four blades. The *six-cut finish* is produced by following the four-cut finish with six blades in the hammer. The *eight-cut finish* follows the six-cut finish and the process is sometimes continued, forming ten- and twelve-cut finishes but these finishes are rarely used on building stone. Pneumatic surfacing machines may be used to produce the same finish as the hand hammers just described, especially for the larger surfaces. Sawed surfaces may be given a hammered finish without the preliminary work of pointing which is necessary on rough surfaces. Finishes produced by the parallel blades of the patent hammer appear to be uniformly corrugated, but the hammer marks are not necessarily continuous. The marks are usually made vertical on wall surfaces; but on molded surfaces they are made parallel to the direction of the molding, and on the top surfaces of sills, steps, washes, and copings they are made perpendicular to the length. Hammered faces of one form or another are commonly used on granite and the harder limestones and sandstones but are not suitable for the softer varieties of limestone.

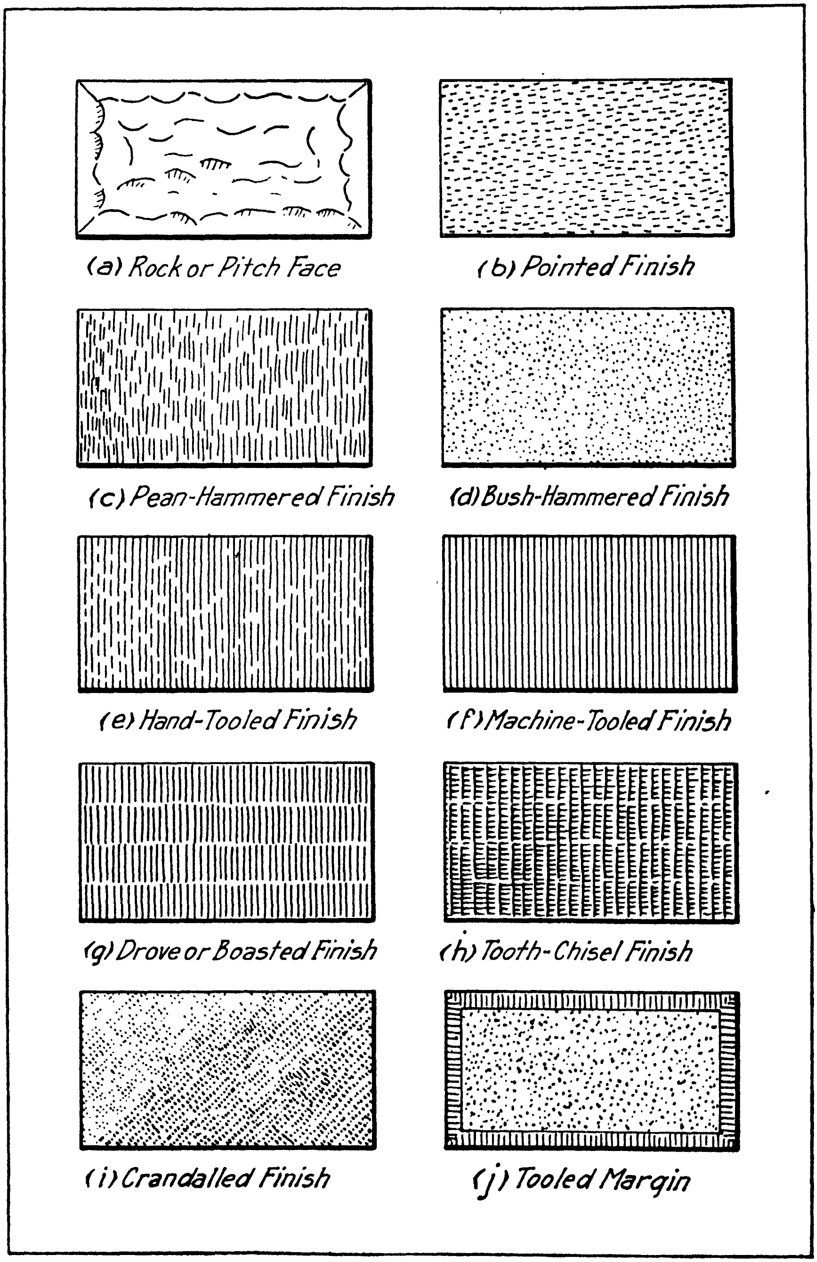


FIG. 75. Stone Finishes

The *tooled finish,* shown in Fig. 75*e*, consists of parallel corrugations or bats produced by hand with a chisel about 4 in. wide. The tooled finish shown in Fig. 75*f* is produced on a planer with a corrugated tool. These finishes are designated as 4 *bats* to the inch, 6 bats to the inch, etc., depending upon the number of corrugations or tool marks to the inch. Tool marks are given the same direction as the hammer marks just described.

The *drove* or *boasted finish,* shown in Fig. 75*g*, is similar to the hand-tooled finish, but it has several series of corrugations on the width of the face instead of on one group in which the corrugations are more or less continuous. The drove finish is produced with a chisel about 2 in. wide, known as a *drove* or *boaster.* The tool marks are often made diagonally.

The *tooth-chisel finish,* shown in Fig. 75*h*, is similar to the hand-tooled and drove finishes but has fine corrugations at right angles to the corrugations of these finishes. The two sets of corrugations are produced by using a toothed chisel instead of the plain chisel or drove.

A *sawed finish* is the surface produced by the saws in cutting a stone to size. The marks of the saws are visible.

A *smooth finish* is produced by planers without hand work other than the removal of objectionable tool marks.

Rubbed and *honed finishes* are produced by grinding or rubbing a sawed or pointed surface by hand or machine, small surfaces and moldings usually being finished by hand. The grade of rubbing is determined by the extent to which this process is carried. Coarse rubbed finish will show small scratches, but a honed finish gives a smooth dead surface practically free from scratches.

A *polished finish* is secured by polishing surfaces which have been previously honed. Granite and marble will take and hold a polish but most other stones will not.

The *margin* or *border* of a stone may have one type of finish and the remaining area may be another type, as shown in Fig. 75*j* — a tooled margin with the remainder of the surface bush-hammered. Stones finished in this manner are called *drafted stones.*

Sand blasting is used to cut lettering and designs into the surface of granite. In this operation, the polished surface is coated with a molten rubberlike compound called *dope,* which solidifies to form an elastic covering. The design to be executed is cut into this covering with a sharp tool exposing the stone surface which is to be cut. A blast of sand is then blown with compressed air through a nozzle and against the stone. The part which is covered with the elastic coating is un-

affected, while the exposed stone is cut as deeply as desired. As stated by Bowles:[9]

The delicate and exquisite detail attained would be impossible with hand tools, and the time required is reduced to a mere fraction of that which hand carving demands.

Selecting Surface Finish. The proper finish to be used depends upon the type of masonry, kind of stone — its position and use in the building, the architectural effect desired, the atmospheric conditions, and the money available.

All the types of finish just described may be used on granite and marble and, with the exception of polishing, they may be used on sandstone and limestone. Limestone which can be polished is usually classed as marble. The hammered finishes are suitable only for the harder sandstones and limestones, for on the softer stones the ridges will not stand up but will break off leaving a bruised face. These finishes are often called *hard-stone finishes* for they are not suitable for soft stone. The tooled finishes are similar to the hammered finishes and are more suitable for soft stones.

In selecting a finish, the type which will give the desired results for the least cost would naturally be used. Very satisfactory results are often produced at low cost with quarry, seam, or split-face rubble masonry.

In general, rubble masonry will be quarry-face; squared-stone masonry will be quarry-face or pitched-face; and ashlar or cut-stone masonry will have a pointed or hammered face if granite and a sawed, smooth, or rubbed face if limestone or sandstone. Marble will usually be rubbed or honed for exterior use, and either honed or polished for interior use. A quarry face or pitch face may also be used for ashlar.

The hammered face of granite will usually be six-cut, but four-cut finish above the second story looks about the same from the ground as six-cut.

On account of the ease in cleaning, polished surfaces are often used for the base courses and other parts which may be splashed with mud by passing vehicles and for lower stories exposed to a smoky atmosphere. The fine finishes keep clean longer than the coarse finishes.

The sawed finish is the cheapest finish for limestone and sandstone, except the harder grades. The standard finish for Indiana limestone is the smooth finish. Machine-tooled finish is usually four, six, or eight bats to the inch. Two-bat tooling may be used on large-scale work, and ten-bat tooling when a specially fine tooling is desired. Hand-pointed finishes are often used on limestone as well as on sandstone and granite.

The finer finishes are more suitable for use on interior surfaces than the coarser finishes; but on the exterior the finer finishes will not show if used above the first story, so that the cheaper finishes are more suitable.

Washes and Drips. The exposed top surfaces of cornices, copings, belt courses, sills, steps, platforms, and other stones which should shed water are provided with sloping surfaces called *washes*. See Fig. 72*b*.

Projecting stones such as cornices, belt courses, and sills are provided with a groove or channel on the under surface of the projection and near the outer edge. This groove is called a *drip* for it causes water to drip from the lower edge of the projecting stone rather than follow along the surface of the wall. Drips should be at least ½ in. wide by ¼ in. deep, but larger drips are better if they can be provided. See Fig. 72*b*.

The stonework will usually be soiled or streaked where the washes pitch toward the face of the stonework. For this reason it is desirable that copings pitch toward the roof and that the water be drained off of projecting stones rather than be allowed to run over the face of the stone even though it drips from the lower edge. See Fig. 72*c*.

Where other work is built on stones provided with a wash, it will usually be necessary to cut *raised seats* and *lugs* on the stones to form level beds for the work which is built on them. See Fig. 72*d*.

Classification of Stone Masonry. In classifying stone masonry, it is necessary to take into account the degree of refinement used in shaping the stones, the way the face stones are arranged in the wall, and the surface finish of the stones.

There are no accepted standards for classification, but in general the crudest type of masonry, constructed of stones with little or no shaping, is called *rubble*, and the highest type, constructed of stones accurately shaped so as to make thin joints possible, is called *ashlar*. Between these two extremes, there are various degrees of refinement in shaping the stones and many ways of arranging them in the wall. The most common classification divides masonry into *rubble*, *squared-stone masonry*, and *ashlar*, according to the care used in shaping the stones, and into *range*, *broken range*, and *random*, according to the arrangement of the stones in the wall. The latter classification does not apply to rubble. Rubble is classed as *coursed* and *uncoursed*. Ashlar is also called *cut stone*. See Fig. 76.

There is no definite line of demarkation between ashlar and squared-stone masonry or between squared-stone masonry and rubble. When stratified stone is used, the horizontal joints of rubble may be as narrow and as uniform as those of squared-stone masonry and the distinction between the two classes would lie in the vertical joints. If the work

done on such stone consists only of knocking off loose rock or sharp corners, rubble would probably result; but, if the stone is shaped to give a uniform vertical joint, squared-stone masonry would be produced. If the end joints are not vertical but are uniform in thickness, the class of work would be the same as that on squared-stone masonry; but such masonry could not logically be placed in that class because of the shape of the stone.

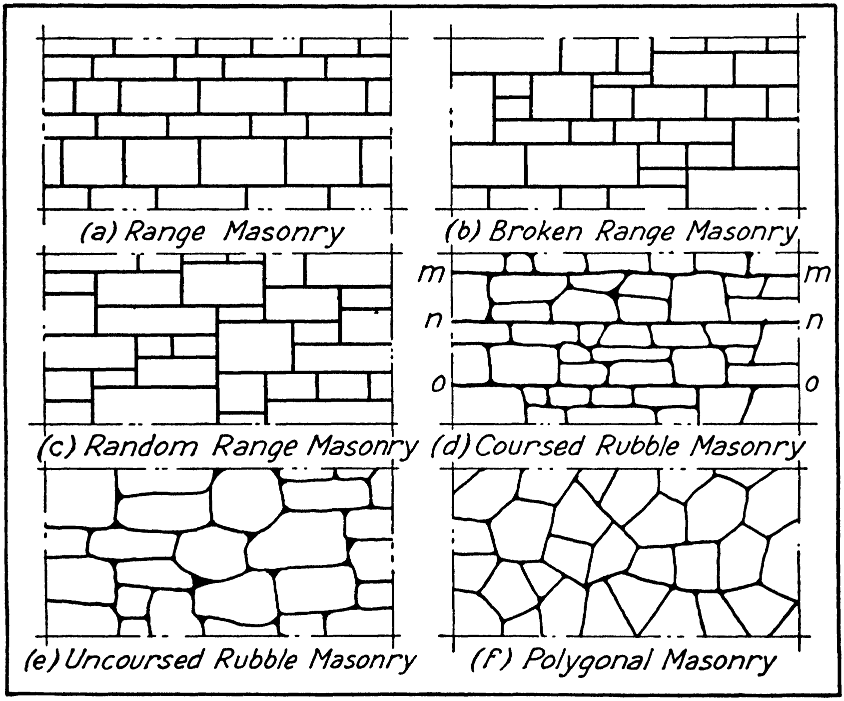


FIG. 76. Classes of Stone Masonry

In some cases the joints are as thin as ashlar joints but the end joints are not vertical. Such masonry should probably be classed as ashlar. If the stones are irregular in shape without parallel surfaces and are shaped to fit the spaces they are to occupy, the joints may be neither vertical nor horizontal. Such masonry is classed as *polygonal masonry* on account of the shape of the face of the stone. In this type of masonry the stones are sometimes accurately cut with joints as uniform and as thin as in ashlar. Often the stones are only roughly shaped and the joints are not uniform in thickness. This type of masonry is often called *mosaic rubble* or *cobweb rubble*. The Building Code

Committee of the Department of Commerce recommends the following classification:[1]

Ashlar Masonry. Masonry of sawed, dressed, tooled, or quarry-face stone with proper bond.

Ashlar Facing. Sawed or dressed squared stones used in facing masonry walls.

Random Ashlar Facing. Sawed or dressed squared stones of various sizes properly bonded or fitted with close joints used for the facing of masonry walls.

Coursed Rubble. Masonry composed of roughly shaped stones fitting approximately on level beds and well bonded.

Random Rubble. Masonry composed of roughly shaped stone laid without regularity of coursing, but fitting together to form well-defined joints.

Rough or Ordinary Rubble. Masonry composed of unsquared or field stones laid without regularity of coursing.

Squared-stone masonry laid in regular courses with the stones roughly squared with a hammer is sometimes called *block-in-course* masonry or *hammer-dressed ashlar.*

Arrangement of Courses. In *range masonry* the stones are laid in courses, each course being uniform in thickness throughout its length. All courses, however, need not be of the same thickness. See Fig. 76*a*.

In *broken-range masonry* the stones are laid in courses but the courses are continuous for short distances only. See Fig. 76*b*.

In *random masonry* no attempt is made to form courses. See Fig. 76*c*.

The terms range, broken range, and random are usually applied only to ashlar and squared-stone masonry; but, where rubble masonry is constructed of stratified stones, the upper and lower surfaces may be parallel and random masonry results. In general, however, rubble masonry is divided into coursed and uncoursed rubble.

In *coursed rubble* the masonry is leveled at specified heights as shown in Fig. 76*d* or is laid in fairly regular courses marked *m–m, n–n, o–o* in the figure.

In *uncoursed rubble* the masonry is not leveled as in coursed rubble. See Fig. 76*e*.

In *polygonal masonry* the stones are irregular in shape without parallel edges and are shaped to fit the spaces they are to occupy, the joints being more or less uniform in thickness. See Fig. 76*f*. This type of masonry is also called *mosaic rubble* and *cobweb rubble*. It is undesirable structurally and architecturally.

Backing. In rubble masonry the face and backing are usually of rubble, the better stones being picked out for the face, but concrete backing may be used.

The backing for squared-stone masonry and ashlar masonry may be rubble masonry, brick, or hollow tile. Rubble masonry is not suitable for backing thin walls such as inclosure walls. If rough blocks are shipped to the building site and are there worked into shape the stone which would otherwise be wasted is used in the rubble backing. Ashlar or squared-stone masonry is not used for backing.

Concrete is also used for backing but it should not be placed against limestone facing or against brickwork in contact with such stone without providing a waterproof layer between the stone and the concrete. If such a layer is not provided, the stone may be discolored and stained. Certain stones may not require such a coating but it should not be omitted without making a thorough investigation. Ashlar is often used as a veneer for concrete walls or other surfaces which are already in place.

The stones used in facing over brick- or hollow-tile backing should preferably be of such a height that they will work in with the backing, the horizontal joints of the face and backing coming at the same level at the intervals desired for bonding as described in the next section.

For illustrations of walls with stone facing and hollow-tile backing see Art. 27.

Setting. The placing of stone in position in a structure is called *setting*. Stones are usually lifted with derricks, the stone being held with *grab hooks*, as shown in Fig. 77*a*, with *lewises*, as shown Fig. 77*b*, or with *pin lewises* inserted in inclined holes, as shown in Fig. 77*c*. If lewises are used, *lewis holes* must be provided. Some contractors use lewises for all stones weighing over 75 or 100 lb. on account of the greater convenience and safety of this method, while others use grab hooks for stones as heavy as 400 lb. The most common type of lewis is assembled in the hole, as shown in *1, 2, 3,* and *4* of Fig. 77*b*.

Stratified stone should be dressed in such a manner that it may be set in the building with the natural quarry bed horizontal. This is important in stratified stone because of its greater strength when it is placed in that direction and also on account of its greater resistance to weathering. When the quarry bed is placed vertical, water enters the stone more freely and weathering progresses more rapidly than when the quarry bed is horizontal. If the quarry bed is placed vertical and parallel to the face, many stones scale off very badly.

The Indiana Limestone Company states that little attention need be paid to the setting of its product on its natural quarry bed. The great majority of such ashlar is sawed with the grain parallel to the face of the wall and monolithic columns are produced with the grain running vertical. However, most limestones are somewhat weaker, when

loaded, parallel to the bedding than when the loading is perpendicular to the bedding.[10]

Door and window sills which have their ends built into the masonry should be bedded only at the ends, the space between being left entirely free from mortar except for the pointing mortar which is applied later. If this practice is not followed, the sills will be quite certain to break when the ends become loaded as the work progresses. This type of sill is called a *lug sill*. Very often window sills are made slightly shorter than the opening and are independent of the rest of the masonry, except, of course, of the bed on which they rest. In this case, the bed is com-

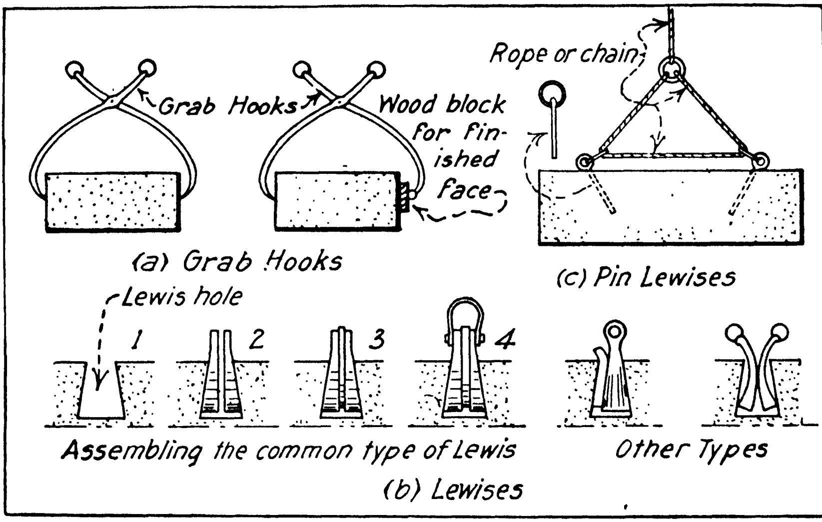


FIG. 77. Methods of Lifting Stone Blocks

pletely filled with mortar. Such sills are called *slip sills*. Exterior steps and sills are set with a slight pitch to the front so that they will drain. Stones projecting beyond the face of the wall should not be set until the mortar in the courses underneath has hardened and should be propped up until the wall above is built.

The following comments on setting are adapted from the *Indiana Limestone Manual* prepared by the Indiana Limestone Company.

In order to insure a uniform joint thickness, it is common practice to place wood wedges at the front side of the mortar joint after the mortar has been placed. One wedge is placed near each end of each stone. As the stone is lowered onto the mortar bed, it squeezes the soft mortar out until the stone finally rests on the wedges. After the mortar has set and before the joints are pointed the wedges are removed. To avoid

their swelling in the wall and to make their removal possible, the wedges must be soaked just before they are used. As they dry out they shrink and become loose, the load then being carried by the mortar which has now had time to set. If the wedges are not thoroughly soaked before placing, they will absorb water from the mortar and swell in the wall. This may result in lifting the stone, with the wall load it now carries, off of the mortar bed. This causes the edges to spall off the stone where they bear on the wedges. It will also make the removal of the wedges impossible; thus they must be broken off so as to clear the pointing mortar. The wedges should be made of soft pine or spruce and should be about $2\frac{1}{2}$ in. long, $\frac{7}{8}$ in. wide, and taper from $\frac{1}{2}$ in. to $\frac{1}{8}$ in. Wedges may be necessary to set stones with uneven beds or to prevent the crushing out of mortar when setting heavy stones. Ordinarily their use with stones having even beds is objectionable, for they often result in improper bedding.

For setting large blocks of stone such as column sections, instead of using wedges three lead pads or buttons are placed in each joint. These pads are about 2 in. square and equal in thickness to the thickness of the joint. Mortar is placed in the joint around these pads, taking care to keep the mortar off of the tops of the pads. To insure the complete filling of the joints, mortar is worked into the joint with an old saw or a mortar saber after the stone is placed.

Heavy column sections are sometimes set on sheet lead pads without mortar except for the pointing. To allow for pointing the pad is made about $\frac{3}{4}$ in. smaller all around than the stone. A hole is cut in the center of the pad to permit the lead to squeeze toward the center, as well as outward, as the pad deforms to an even bearing.

Thin ashlar facing should not be carried up more than two courses in advance of the backing, and no bond stone or other stone having a wider bed than the stone directly below it should be set until the backing has been built up level with the top of the lower stone.

Care must be used to insure that the wall loads of skeleton steel or concrete buildings are carried by the frame and not by the walls themselves. This may be accomplished by starting the work at two or three levels in the upper stories. It is desirable to leave the lower stories until the last to avoid their receiving excessive loads from the stories above as the structural frame deforms under the increasing dead load.

A waterproof membrane of tar paper and a bituminous cement or of slate should be provided on top of the foundation wall and under the base course to keep moisture from being carried into the lower courses of the masonry by capillary attraction and causing efflorescence, stain, and disintegration. When using any so-called soft stone possessing

comparatively high absorption for any work in contact with grade, it is desirable that the base course be coated with a colorless waterproofing.

In general, stone setting should not be done when the temperature is below 20 deg., or below 25 deg. when the temperature is falling. During cold weather the mortar sand should be dried out and heated and the water should be heated. The mortar should be used while it is warm. If any ice or frost is on a stone, it should be steamed off before setting the stones. Salt should not be used to remove ice from lewis holes or anchor holes. Neither should it be used for any other purpose, for it will cause efflorescence. Stone covered with ice should be taken into a warm place and be allowed to thaw and dry.

Bond Stones and Anchors. In stone masonry, longitudinal bond is secured by breaking joints as in brick masonry, although in broken range and random masonry a vertical joint may sometimes be three stones in height.

Bond between the face and backing may be secured by headers or bond stones as in brick masonry, by bond courses, by metal anchors, or by bond courses or stones and metal anchors used together.

The bond or anchorage required between the face and backing depends upon whether the wall is a bearing wall or a non-bearing wall and upon whether the facing is to be considered in the required thickness of the wall.

Headers extending entirely through the wall, as shown in Fig. 78*a*, provide an effective method of bonding and are suitable for use in bearing walls.

Bond stones arranged in courses projecting into the backing an amount equal to the thickness of the other facing stones, as shown in Fig. 78*b*, and with one bed of every stone in contact with a bond stone will tie the face stone to the backing securely enough for non-bearing walls where the facing is not considered as a part of the required thickness of the wall. The arrangement shown in Fig. 78*c* makes every other course a bond course. This provides a more secure bonding between the facing and the backing, but is not usually considered suitable for bearing walls if the facing is required to carry its share of the load. All the stones in a bond course are not usually bond stones; and in broken range and random masonry the bond stones are distributed at random throughout the wall, with each stone providing the tie for a given surface area.

Metal anchors are extensively used to tie the facing to the backing, as shown in Fig. 78*d*. When this method of anchoring is used on bearing walls, the facing can not be considered as carrying any part of the load and it can not be included in the required thickness for any type of wall.

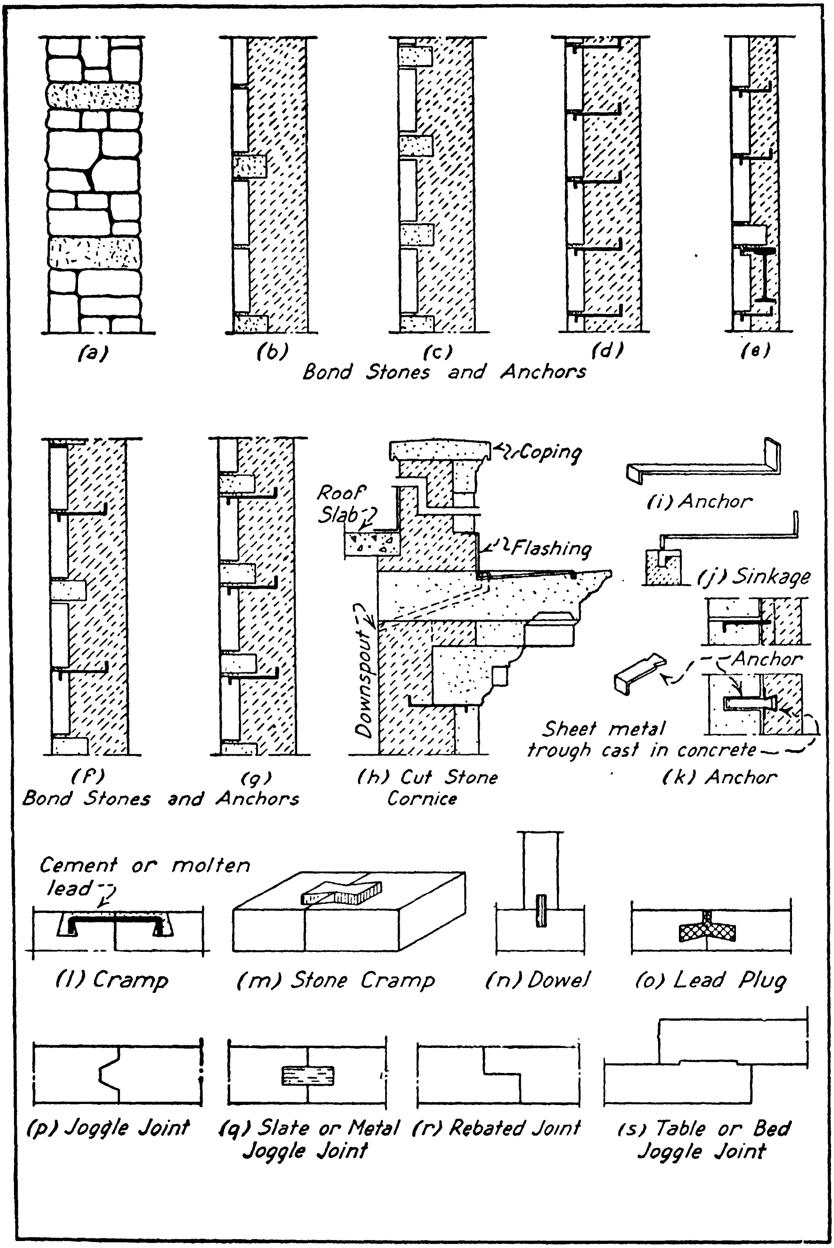


FIG. 78. Bonding and Anchoring Stone Masonry

Bond courses and anchors are commonly used together. In Fig. 78*e* the anchors are supplemented by a bond course bearing on the spandrel beam of each story. This type of construction is desirable for panel and inclosure walls in skeleton construction. Such walls are commonly 12 in. thick and may require that anchors extend entirely through the backing for adequate bond, the upturned end being against the inner face.

The combination of bond courses and anchors shown in Fig. 78*f* is quite effective, but, if the facing of bearing walls is to be considered as carrying its share of the load and is to be considered in the required thickness, every alternate course should contain bond stones and every stone not a bond stone should be anchored to the backing, as shown in Fig. 78*g*. The bond stones should occupy at least 20 per cent of the wall surface. If stones are not in courses, the equivalent bonding should be provided.

The method of anchoring a cut-stone cornice is illustrated in Fig. 78*h*. Special anchors should be provided for cornice and belt-course stones that do not have sufficient bearing to balance on the wall. These anchors should be hooked into the stone at least 2 in. and should be spaced about 2 ft. apart, with at least two anchors to a stone.

Further discussion of the bond required between the facing and backing is given in the paragraph on Faced Walls and Veneered Walls.

Construction and Placing of Anchors. Anchors are usually placed in the horizontal joints and hooked into the tops of the stones, but at times it is desirable to place anchors in the vertical joints near the top and near the bottom of the stone and hooking into the side, especially when hollow tile backing is used. A typical form of anchor is shown in Fig. 78*i*.

Anchors should not be placed in the mortar joint, but a *sinkage* or depression of ample width and of a depth slightly greater than the thickness of the anchor should be provided at the back of anchor holes, as shown in Fig. 78*j*. There are two reasons for providing sinkages. With the ¼-in. joints usually used in ashlar masonry there would be difficulty in placing the anchors in the joints and the stones would tend to rest on the anchors rather than to secure uniform bearing on the mortar joint. This condition would tend to cause the stones to crack. The sinkages do not fit the anchor accurately but are usually larger than necessary and are crudely formed. Anchor holes should be kept about 2 in. from the outer surface of the stonework in order that the anchor may be adequately protected.

Anchors should be made of wrought iron or soft steel galvanized after cutting and shaping. Galvanizing is required to prevent rusting, which

may stain the stonework, split the stone by expansion while rusting, or finally destroy the anchor. The coating of anchors with paint will not take the place of galvanizing but may be done as an additional precaution.

For ashlar and other ordinary facing stone, the Indiana Limestone Company recommends anchors $\frac{3}{16}$ in. thick by 1 in. wide, having one end bent down a scant inch into the stone and the other end bent up a full 2 in. into the backing, and of a length that will extend from the anchor hole a distance of about $8\frac{1}{2}$ in. into the brickwork where brick is used for backing or to hook over the center web of hollow tile where tile is used for backing. For very high courses or heavy work, anchors $\frac{1}{4}$ in. thick by $1\frac{1}{4}$ in. wide may be used or even $\frac{3}{8}$ in. by 2 in. for special purposes, but such heavy anchors are seldom necessary.

The anchors recommended by the National Building Granite Association are $\frac{1}{4}$ in. by $1\frac{1}{4}$ in. turned down into the granite about $1\frac{1}{4}$ in. and extending into the backing 8 in. if the thickness of the wall permits, the end being turned up $1\frac{1}{2}$ in. into the backing.

For anchoring stone facing to concrete columns or to steel columns fireproofed with concrete, $\frac{3}{8}$-in. round or square galvanized steel rods may be used. These should be hooked down 2 in. into a hole drilled into the stone at one side and may be bent around the column and be hooked in a similar manner at the other side, or may be hooked into a hole drilled into the concrete on the side of the column, an anchor being used on each side. These anchors are bent and cut to size on the job.

A patented form of anchor which is very convenient for use in anchoring a stone facing to a concrete wall is shown in Fig. 78*k*. Before the wall is poured, sheet-metal troughs are tacked to the side of the form for the outer face. These are placed vertically and at the proper intervals. When the forms are removed the trough is exposed in the face of the wall. It is beveled on the sides to receive an anchor with a dovetailed end, as shown in the figure. The anchors may be moved up and down to fit into the joints. This type of anchor is more convenient and much more effective than most types of anchors which are cast in concrete walls and are bent out into the mortar joints of the facing.

Lewis Anchors, Cramps, Dowels, etc. Forms of anchors, other than those just described, are sometimes required. When it is necessary to suspend the soffits of openings from steelwork above, lewis anchors similar to the ordinary lewis, are used. The lewis holes for the anchors should be from 3 to 4 in. deep.

Clamps or *cramps* are used to keep coping stones, stair rails, etc., from pulling apart. They are made of flat iron, varying from $1\frac{1}{4}$ by $\frac{1}{4}$ in. for light work to $1\frac{1}{2}$ by $\frac{1}{2}$ in. for heavier pieces. These are turned down

$1\frac{1}{2}$ or 2 in. at the ends and vary in length from 6 to 12 in. They may be set in sinkages in the tops of the stones or they may be set under the stones with their ends turned upward into the stones. *Cramps* should be heavily galvanized after being bent to shape. On high-class work they may be protected by pouring molten lead around them, as shown in Fig. 78*l*, the holes being larger at the bottom than at the top in order to hold the lead and anchor in place. Cramps or keys made of slate or other stone or of metal may occasionally be used in place of cramps, as shown in Fig. 78*m*. The lead plug shown in Fig. 78*o* serves the same purpose but is rarely used. In forming the lead plug, molten lead is poured in the vertical channel and fills the dovetailed holes sloped so that the lead can easily fill the holes. Brass or bronze dowels made of solid rods or of pipe are commonly used to hold the ends of balusters, window mullions, and similar pieces in position as shown in Fig. 78*n*. The ends of inclined copings may be doweled into the kneelers, as shown in Fig. 59*e*.

Joggled, Tabled, and Rebated Joints. Two types of joints which are rarely used are the *joggled joint* shown in Fig. 78*p* and the *table joint* or *bed joggle joint* shown in Fig. 78*s*, designed to prevent movement along a joint. These joints are very expensive to form. A slate or metal joggle joint, as shown in Fig. 78*q*, may be formed more cheaply. The joint is not usually continuous. A *rebated joint* is shown in Fig. 78*r*. This type of joint is sometimes used for coping stones placed on a slope.

Faced and Veneered Walls. Stone walls may be classed as faced walls and veneered walls according to the provision which is made for bonding the face to the backing. If the facing and backing are securely bonded together so that they will act as a unit, the entire thickness of the wall may be considered in strength calculations and in satisfying the requirements for minimum thickness. Such walls are called *faced walls*. If the facing is not attached and bonded to the backing to such an extent as to form an integral part of the wall, the wall is called a *veneered wall* and only the backing may be considered in strength calculations and in satisfying the requirements for minimum thickness.

Building codes differ very greatly in their requirements for bond and anchorage. The following requirements are taken from the Report of the Building Code Committee of the Department of Commerce entitled "Recommended Minimum Requirements for Masonry Wall Construction."[1]

Requirements for Faced Walls. Materials used for facing shall be not less than $3\frac{3}{4}$ in. thick, and in no case less in thickness than $\frac{1}{8}$ the height of the unit, excepting that spandrel and other recessed panels, when approved, may

be higher than 8 times their thickness, provided they are of the minimum thickness required.

The maximum allowable compressive stresses on faced walls due to combined live and dead loads shall not exceed those elsewhere prescribed for masonry of the type which forms the backing. Where properly bonded to the backing the full cross-section of the facing may be considered in computing bearing strength.

Faced walls shall be not less in thickness than is required for masonry walls of the type which forms the backing. Where properly bonded to the backing, the facing may be considered a part of the wall thickness.

Stone-ashlar facing shall have at least 20 per cent of the superficial area not less than $3\frac{3}{4}$ in. thicker than the remainder of the facing to form bond stones, which shall be uniformly distributed throughout the wall.

When bond stones in every alternate course are at least $7\frac{1}{2}$ in. thick, bonded into the backing at least $3\frac{3}{4}$ in., and at least 20 per cent of the superficial area of the wall is constituted of such bond stones uniformly distributed, the ashlar facing may be counted as part of the wall thickness. Every stone not a bond stone and every projecting stone shall be securely anchored to the backing with substantial non-corrodible metal anchors.

Anchors for attachment of facing or veneering to the backing should be not less than $\frac{3}{16}$ by 1 in. in cross-section, and should either be bent or of sufficient length to develop their full strength in bond. Such anchors should be thoroughly protected from moisture, or should be of non-corrodible metal.

A faced wall is illustrated in Fig. 78*g*.

Requirements for Veneered Walls. Stone or architectural terra cotta ashlar, or other approved masonry material used for veneering, shall be not less than 3 in. thick. In stone ashlar each stone shall have a reasonably uniform thickness, but all stones need not necessarily be the same thickness.

The maximum allowable compressive stresses on the backing of veneered walls, due to combined live and dead loads, shall not exceed those prescribed for masonry of the type which forms such backing. In no case shall the veneering be considered a part of the wall in computing the strength of bearing walls, nor shall it be considered a part of the required thickness of the wall.

When walls are veneered with brick, terra cotta, stone or concrete trim stone, the veneering shall be tied into the backing either by a header for every 300 sq. in. of wall surface, or by substantial non-corrodible metal wall ties spaced not farther apart than 1 ft. vertically and 2 ft. horizontally. Headers shall project at least $3\frac{3}{4}$ in. into the backing, and anchors shall be of substantial pattern. When veneering is used special care shall be taken to fill all joints flush with mortar around wall openings.

Veneered walls shall not exceed 40 ft. in height above foundations.

Veneered walls are illustrated in Fig. 78*b* to *e*.

The panel walls of skeleton construction buildings are carried on the structural frame and are usually veneered walls with hollow tile or brick

backing. Such walls should have one bond course placed directly on the spandrel beams. One bond course to a story may be sufficient but sometimes it is advisable to use two or the equivalent. Many building codes do not require any bond courses for panel walls, but this is poor practice. A panel wall resting on a steel spandrel beam is shown in Fig. 78*e*.

Joints and Pointing. The mortar layers between stones are called *joints*. Horizontal joints are *bed joints* or simply *beds,* and vertical joints are known as *joints* or *builds*.

In rubble masonry the joints are neither uniform in thickness nor constant in direction but they simply fill the spaces between stones of irregular shape. Large spaces in the backing may have small pieces of stone called *spalls* embedded in the mortar.

In squared-stone masonry the joints are horizontal and vertical and are more or less uniform in thickness, the stones having been roughly dressed to shape. In general the joints in squared-stone masonry will be $\frac{1}{2}$ in. to 1 in. in thickness.

In ashlar or cut-stone masonry the stones are accurately dressed to shape so that the joints do not exceed $\frac{1}{2}$ in. in thickness. A very common thickness of joint for the ashlar facing of buildings is $\frac{1}{4}$ in. Joints $\frac{1}{8}$ in. in thickness are sometimes used for interior stonework but are not desirable for exterior work.

The mortar in the horizontal and vertical joints of ashlar masonry is kept back from the face in setting the stone or is raked out to a depth of about $\frac{3}{4}$ in. In this space a special mortar is placed to make a tighter and more attractive joint. This process is known as *pointing*. The various types of joints formed by pointing are shown in Fig. 79. Pointing is done after the mortar in the joint has set and usually after all the stone has been placed and the wall has received its full load.

Squared-stone masonry may be pointed in the same manner as ashlar, or the joint may be finished at the time the stone is set.

The joints in rubble masonry are usually finished when the stones are set and no pointing is done.

Often the joints of squared-stone masonry or rubble are made flush with the surface of the stones and after the mortar has set a narrow bead of colored mortar is run on the wide joints to give the effect of narrow joints. See Fig. 79*b*. The wide joint is frequently made the same color as the stone and the narrow joint a contrasting color.

The joints are often emphasized by shaping the stones, as shown in Fig. 79*c*, to form *rusticated* or *rebated* joints. This type of joint is frequently used in the stonework on the lower stories of buildings to give a massive appearance.

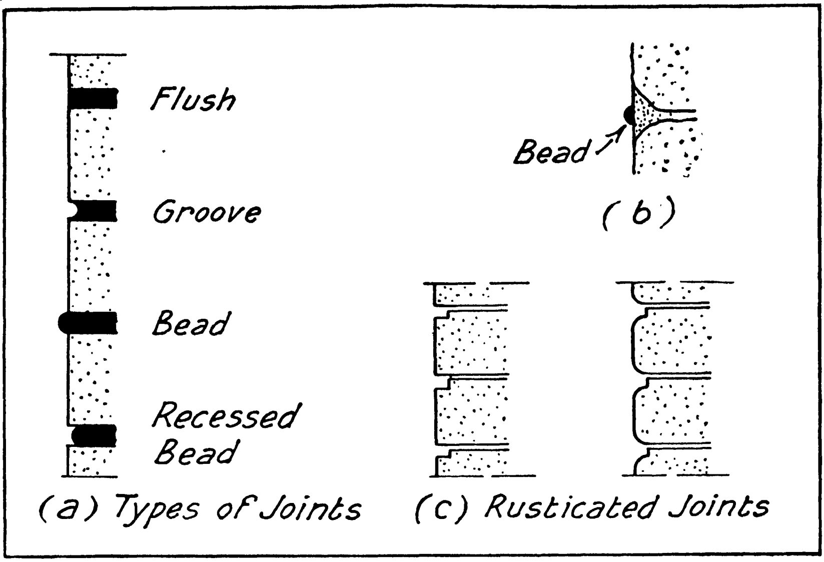


FIG. 79. Joints for Stone Masonry

The following discussion concerning the vertical joints of cornices, copings, etc. is quoted from the *Indiana Limestone Manual.*

It is very important that the vertical joints in all cornices or belt courses projecting from the face of building wall, the top members of all main cornices and copings and balustrade rails be thoroughly filled with setting mortar. Where this is not done, the passage of water is sure to show in some manner on the face of stone and probably disfigure an otherwise fine piece of work.

Vertical joints in such members can not be properly filled simply by slushing up at time of setting, and should always be grouted solid. It is a mistake to make these joints less than a full ¼ in., regardless of the thickness of joints elsewhere throughout the work. The stone should be set with the vertical joints dry, and the exterior profile of the members should be carefully calked with picked oakum or newspapers soaked in water, and the joint should be poured full with as thick a mortar grout as can properly be worked into it, allowing the usual ¾ in. of depth at the top of the joint for pointing up later. With very large stone, it is advisable to cut an inverted V-shaped key channel on vertical joints to facilitate this grouting.

The calking is later removed, and thus provides the necessary space for pointing up of joints. If the grout is too thin, it will tend to shrink away from the stone in setting and the joint may not be tight. To avoid this shrinkage, a proper proportion of sand should always be used and the grout should be continually stirred until used to prevent the separation and settling of the sand.

Large cornice members are sometimes calked with lead wool as an extra precaution. Where this is to be done, the grouting should only fill the joint to

within about 2 in. of the top, and a full inch of this depth should be calked with lead wool, driven in tightly, leaving the upper ¾ in. for pointing mortar.

Sometimes the grouting is dispensed with, the stone being bedded with vertical joints buttered with mortar, and calking with lead wool or oakum relied upon to make them tight, but this is not considered as good practice as the proper grouting of these joints. Lead wool, when used, should supplement and not replace the thorough filling of vertical joints in cornices and other exposed horizontal members.

Still another scheme is to substitute an elastic calking cement for the ¾ in. of pointing mortar on all top surfaces, washes, gutters, etc. Only calking compounds that are light in color and free from oils and grease that would discolor the stone are suitable for this purpose.

The greatest advantage of an elastic calking compound is for calking the coping and parapet walls built on top of modern steel-frame structures, rather than for work in connection with buildings having solid masonry walls, as these skeleton-frame structures are more subject to movement from wind stress and from expansion and contraction of the structural frame.

For certain types of step and platform work, in connection with approaches and other outside work, the filling of vertical joints with mortar is not desirable as slight movements in the supporting masonry will often be caused, not only by frost action but by seasonal moisture conditions in the surrounding soil. For such work a lead joint is then desirable. This may be specified, as follows:

The joints in all steps and platform slabs shall be calked on the underside with oakum or rope yarn and then be filled with molten lead, well pounded in and completely filling the joint so as to finish smooth with the surface of the stone.

Flashing. Special calking in the vertical joints of copings, projecting corners, cornices, sills, etc., is less necessary if flashing, illustrated in Fig. 64, can be used to keep water out of the vertical joints or to conduct it out of the wall by flashing immediately below the member.

Mortar. Stone masonry should usually be set in cement mortar consisting of 1 part portland cement to 3 parts sand. If lime is used to increase the workability of the mortar, not more than 15 per cent of the volume of the cement should be replaced by an equal volume of lime.

Ordinary portland-cement mortar will stain limestone and some other stones; so, for setting facings of such stones, non-staining white portland-cement mortar or lime mortar may be used. In any case, the possibility of mortar's staining face stone should be investigated before selecting the mortar.

A cement-lime mortar which will not stain light-colored stone consists of 1 part of non-staining cement, 1 part of hydrated lime or lump-lime paste, and not over 6 parts of sand. The sand must be clean, and both sand and water must be free from all elements that would tend to cause staining of the stone.

The addition of the white portland cement to lime mortar is necessary to hasten the setting. In some cases a lime-cement mortar may be used. This mortar should consist of 1 part lime, 1 part non-staining cement, and 6 parts of washed sand.

Many building codes require portland-cement mortar for ashlar facing as well as for the backing of inclosure and other outside walls.

A mortar made of white non-staining waterproof cement or of an ordinary white non-staining cement with suitable integral waterproofing, used as a *parging* or *pargeting* on the back of stone, is one of the best means of preventing staining from ordinary cement mortar used in laying up the backing.

Foundation walls should always be laid with portland-cement mortar.

The mortar for pointing should not be too rich or it may shrink away from the stone, become loose, and eventually fall from the joints. A mortar consisting of 1 part portland cement (non-staining if required), 2½ parts of fine sand, and about 15 per cent of lime to make the mortar more workable, gives good results for pointing.

Dampproof Coatings and Backpainting. Face stone is commonly protected from stain owing to the mortar in the joints and in the backing by dampproofing in some form. This is particularly necessary for limestone.

The National Building Granite Quarries Association recommends that, at least 12 hours before the granite is set, all surfaces not exposed be thoroughly coated with an approved dampproof compound to within 1 in. of the exposed face, and that after the granite is set, and before backing up, another coat of the same dampproofing be applied to the back for the special purpose of covering the backs of mortar joints. The painting of the granite may be omitted when it is definitely known that the setting mortar will not stain the granite; but the backs of the joints should be dampproofed in any event to guard against seepage, through the joints, of moisture from the mortar or material used in backing the granite work which will cause discoloration around the face joints or on surface of the granite.

The use of dampproof coatings is not recommended by the Indiana Limestone Company for its product. This company recommends that mortar used in the face and backing be such that it will not stain the face stone, the necessity for dampproofing thus being avoided. The plastering of the entire backs of all stone, while wet, with a ½-in. coat of waterproof cement mortar before backing up, is also recommended. This is called parging. When a stone facing is placed against concrete, the concrete and not the stone should be painted with a dampproof compound. Where concrete must be poured behind face stone, this com-

pany recommends that brick or tile be placed against the stone, that the back of this material be dampproofed, and that the concrete be poured against the dampproof backing.

If limestone or other stone which will stain is used as a trim for brick-face walls with the brick facing and other brickwork in contact with the stone, the only way of dampproofing is to backpaint the stone. Moreover, all sides of the stone that are built into the walls should be parged with lime or non-staining cement mortar. These precautions are not necessary if lime mortar or non-staining cement mortar is used for the brickwork.

The top of concrete foundation walls just under the first course of stone should be waterproofed in some manner to prevent moisture in the foundation walls from being drawn up into the stonework and causing staining due to elements contained in the soil. The same results may be less effectively accomplished by placing a layer of asphalt-saturated felt, slate, or sheet lead between the top of the wall and the stonework. Sheet lead will equalize the pressure of the stone on the foundation wall better than felt, but is much more expensive. In all cases, the top of concrete foundation walls should be given a heavy coat of hot asphalt or dampproof paint.

Efflorescence. For a discussion of efflorescence see Art. 25.

Colorless Waterproofing Materials. Colorless waterproofing materials may be used on the surface of stone masonry to keep moisture from penetrating the walls and causing dampness, efflorescence, and disintegration due to frost action and efflorescence. The results of a study of colorless waterproofing compounds by D. W. Kessler are given in Technologic Paper 248 of the Bureau of Standards. The conclusions reached are as follows:

1. The most effective waterproofing materials in this series are those the waterproofing elements of which are heavy petroleum distillates, fatty oils, or insoluble soaps.

2. The effectiveness of any waterproofing may be greatly influenced by the character of the pores in the stone.

3. Stones having close textures are more difficult to waterproof than those with large pores.

4. The treatments giving the highest waterproofing values and appearing to be most durable are those which use paraffin as the waterproofing element, either alone or in conjunction with other materials. The deterioration or loss of waterproofing value of materials of this type is not appreciable within a period of two years.

5. Waterproofing materials employing resinous substances as the waterproofing element are not durable.

6. Materials consisting of aqueous solutions, the purpose of which is to react chemically with the stone or to act merely as water repellents, have only temporary effects.

7. Separate aqueous solutions which react chemically with each other and form insoluble substances in the pores of the stone give low waterproofing values and deteriorate rapidly.

8. In general, those materials which gave the highest waterproofing values produced the greatest discolorations. The amount of this discoloration was proportional to the porosity of the stones. These discolorations decrease on exposure to the weather and after a year or more, depending upon their intensity, they are compensated for by the fact that the treatments tend to prevent the accumulation of dust and soot on the surface of the stone.

Trim Stone. Cut stone is frequently used as a trim around window and door openings and for belt courses, copings, and cornices in walls constructed of brick or rubble masonry. Stone used in this manner is called *trim stone.*

Cast Stone. The use of cast-concrete units, commonly known as *cast stone,* to replace cut stone has been growing in recent years. Cast stone consists of molded blocks of concrete with special surface treatment. They may be formed in any of the shapes obtained by cutting the natural stone and may have surface finishes which resemble the rubbed finish commonly used on limestone and other stones, or any of the tooled finishes. Special aggregates may be used next to the face or for the entire block so that when the cement surface film is removed by etching with acid or tooling the face will resemble granite, marble, and other natural stones, or the aggregate may be chosen simply to produce an attractive finish without attempting to imitate any natural stone.

One of the problems in connection with the manufacture of cast stone is the prevention of *crazing.* Crazing consists of small cracks of web-like nature which often form on the surface of cast stone. Circular 304 of the Bureau of Standards states:

It is the result of volume changes incident to variations in moisture and temperature and the setting of concrete. With very thin rich coatings on relatively lean bodies crazing generally appears. How to prevent crazing on concrete products is a question which is now engaging the attention of many investigators. However, much can be done by the concrete products manufacturer to lessen the tendency to craze by using lean facing mixtures, providing thorough curing, avoiding excessive troweling of surfaces, not using too much water, using coarse surfacing materials, and removing the surface film of cement in which the cracks are often so pronounced. In some cases the use of a different body mix might be helpful. Exposure of fresh concrete to the sun or wind should be avoided.

Stone Arches. Stone arches are extensively used in building construction to span openings in walls and for arcades. The parts of an arch and the various types of arches have been discussed in Art. 24. The stones forming the arch ring are accurately cut to shape, preferably with their bedding planes perpendicular to the arch axis. They are set in cement mortar. The backs of stone arches are commonly stepped, as shown in Fig. 80, to facilitate the joining of the arch stones and the stone courses of the wall.

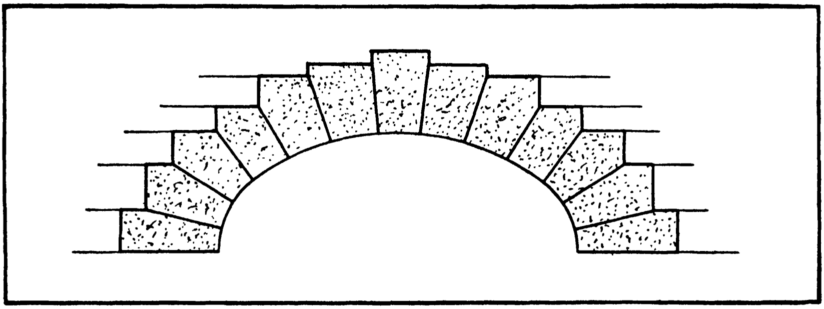


FIG. 80. The Stepped Arch

Minimum Wall Thickness. The factors which affect the thickness of masonry walls are discussed in Art. 24.

The recommendations of the Building Code Committee of the Department of Commerce for stone walls are as follows:[1]

Lateral Support and Thickness. Rubble stone walls shall be 4 in. thicker than is required for solid brick walls of the same respective heights, but in no part less than 16 in.

The minimum thickness for walls or piers of ashlar masonry properly bonded shall be the same as required for solid brick walls and piers under similar conditions. See Art. 25. (Ashlar masonry is defined by the Building Code Committee as "Masonry of sawed, dressed, tooled, or quarry-faced stone with proper bond." It would include squared-stone masonry.)

The lateral support for stone walls shall conform to the same requirements specified for solid brick walls. See Art. 25.

Bond. Bond stones extending through the wall and uniformly distributed shall be provided to the extent of not less than 10 per cent of the area, and there shall be at least one bond stone for every eight stretchers. See the paragraph on Faced and Veneered Walls in this article.

Veneered and Faced Walls. See the paragraph on Faced and Veneered Walls in this article.

Fire Resistance. The fire-resistive ratings of various types of walls are given in Art. 24. The authorities consulted in preparing this material made no mention of stone walls, possibly because of the widely varying fire-resistive properties of building stones, as mentioned in Art. 11.

ARTICLE 27. HOLLOW-TILE AND CONCRETE-BLOCK MASONRY

Classes of Hollow Units. Hollow units made of burned clay or shale, concrete, gypsum, and glass are extensively used in the construction of walls and partitions. The maximum length or height of these units usually does not exceed 12 in., although some are 16 in. long. The common minimum thickness is about 4 in., but some are as thin as 2 in. The terms *tile* and *block*, as used in this sense, are synonymous, but the hollow clay and gypsum products are commonly called *tile*, and the concrete and glass products are usually called *blocks*. The terms tile and block are used to represent a single unit or collectively for a number of such units, as in the case of brick although the term blocks is usually used for the plural. The term *terra cotta*, meaning "burned earth," is often applied to structural clay tile, but this term is preferably reserved for ornamental building units of burned clay which are commonly classed as *architectural terra cotta*, as described in Art. 28. Hollow clay tile is also called *structural clay tile*. Glass blocks are also called brick.

Structural Clay Tile. These units, which are illustrated in Figs. 81 and 82, are manufactured by extruding or forcing a plastic clay through specially formed dies, cutting to the desired dimensions and burning to various degrees of hardness, depending upon the grade being manufactured. The grades are sometimes called hard, medium, and soft, but other designations are used. Sawdust, coal dust or other combustible admixtures may be mixed with the clay and become burned out, during the burning process, forming a *porous structural clay tile*. The hollow spaces in the tile are called *cells*. The outer walls are called the *shells*, and the inner partitions which divide the tile into cells are called *webs*.

Tile are divided into two classes according to the direction of the axes of the cells when the units are placed in masonry. In *side-construction tile*, the cells are placed horizontally, as shown in Fig. 81*a*; whereas in *end-construction tile*, the cells are placed vertically, as in Fig. 81*h*. They are divided into two classes according to the loading conditions. *Load-bearing tile* are designed for use in bearing walls and partitions where they are subjected to loads other than the weight of the wall or partition itself; whereas *non-load-bearing tile* are designed for use in

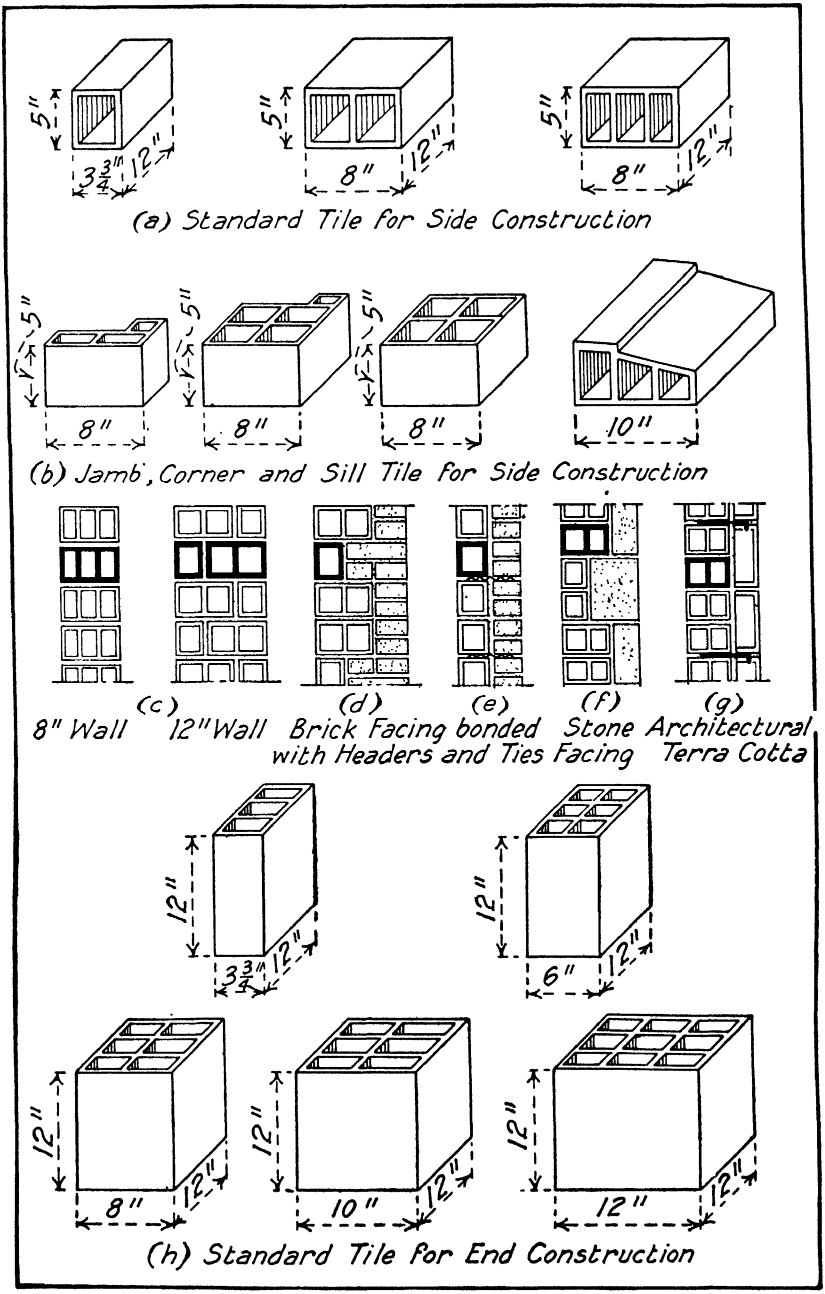


Fig. 81. Hollow-Tile Shapes

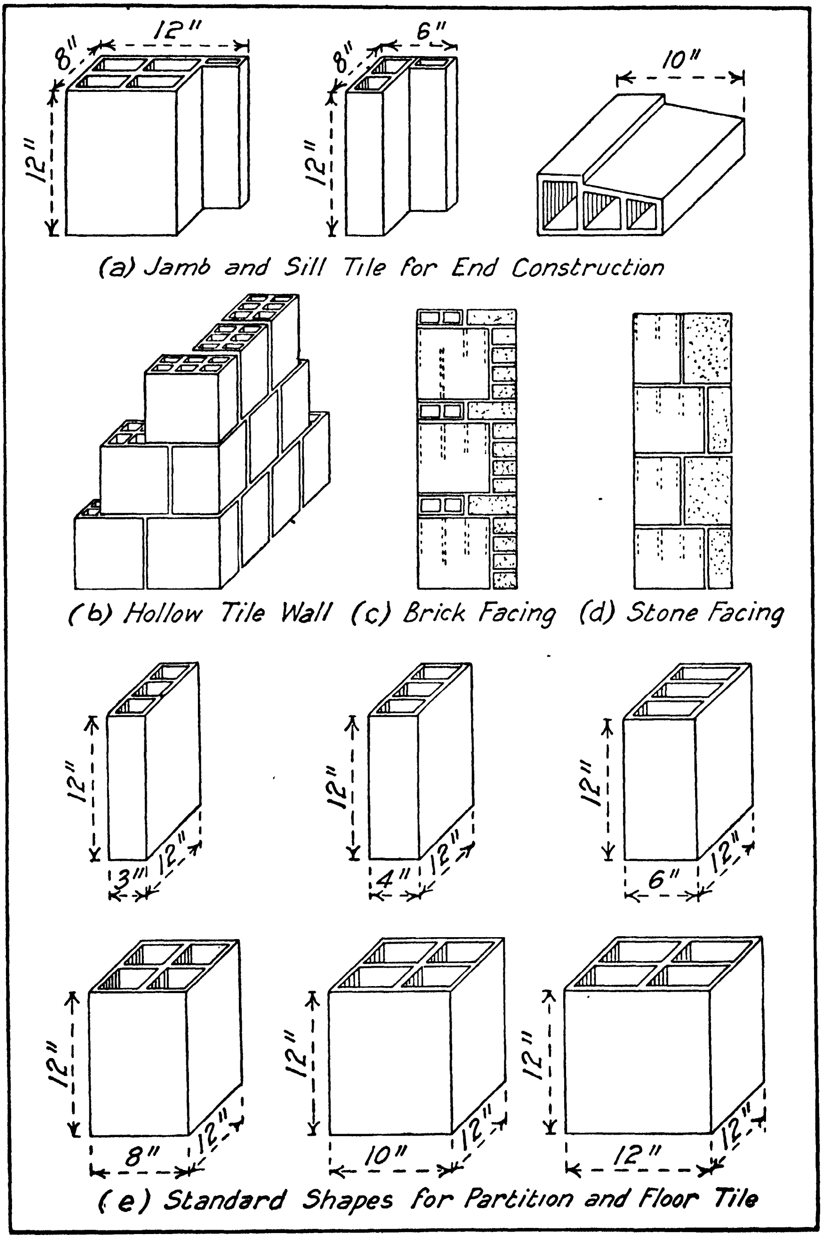


FIG. 82. Hollow-Tile Shapes

non-bearing partitions, panel walls, etc., where they carry only the weight of the wall or partition. The thickness of the shells is commonly required to be at least ¾ in. and the webs ½ in. The dimensions of several sizes of side- and end-construction tile are given in Figs. 81 and 82. Special tile are available for sills and window jambs and for the corners of side construction so that the ends of the cells will not be exposed.

Many patented forms of hollow tile are on the market. Most of these are for side construction. Various advantages are claimed for each tile, as compared with standard tile, such as speed in laying and, as described in the next paragraph, ease in bonding with brick or stone facing.

Structural terra cotta is used for exterior or interior bearing and non-bearing walls and partitions. Tile are available with the exposed surfaces finished, as described in the paragraph on Clay Glazed and Facing Tile; but the exposed faces of regular structural clay tile must be covered with some facing material except in warehouses and garages and in other locations where appearance is not a factor. Surfaces which are to be plastered are *scored*, with parallel scratches, to improve the bond. Wall tile may be bonded to the surface of tile with mortar in the usual manner. Brick, cut stone, architectural terra cotta, and thin marble veneers may be anchored to structural clay tile with metal ties, as shown in Fig. 81*e* and *g*, or brick and stone facings may be bonded to structural clay tile backing, as shown in Fig. 81*d* and *f* and in Fig. 82*c* and *d*.

Clay Glazed and Facing Tile. These clay tile, two forms of which are illustrated in Fig. 83, are made by the same method as structural-clay tile. They are used to form the exposed interior and exterior surfaces of walls and partitions. They include the brick size as well as the larger tile sizes. The finish of the exposed faces of *glazed tile* is either a ceramic glaze, a salt glaze, or clay coating whereas the finish of *facing tile* is unglazed. The *ceramic glaze* is produced by spraying the face with appropriate chemicals and by burning the entire tile at a temperature of about 2000 deg. fahr., fusing the finish to the body of the tile and forming a non-absorbent, acid-resisting face available in matt (or matte) satin, and glossy finishes and in a great variety of colors such as white, cream, tan, gray, red, yellow, blue, green, and black. The *salt glaze* is formed by exposing the face to salt vapor produced by introducing salt into the fire while the units are at a temperature of about 2000 deg. fahr., producing a transparent film of sodium iron silicate which is smooth and lustrous and exposes the gray, cream, or buff color of the fire-clay body. The *clay-coated* finish is a dull non-reflect-

ing finish available in all colors. The finish of facing tile corresponds to that of face brick. Stretchers with two faces finished are available. The backs of units are finished smooth or scored for plaster.

Stretchers are available in the following face sizes:

Height in inches	2¼	3⅞	5	5	5	8	8
Length in inches	8	8	8	10	12	12⅛	16¼

The standard units are all 3⅞ in. wide, but bonding units 5⅞ in. and 8 in. wide are available for stretchers which are 5 in. high. Narrow units 1¾ in. wide, called *soap stretchers,* are available for all sizes.

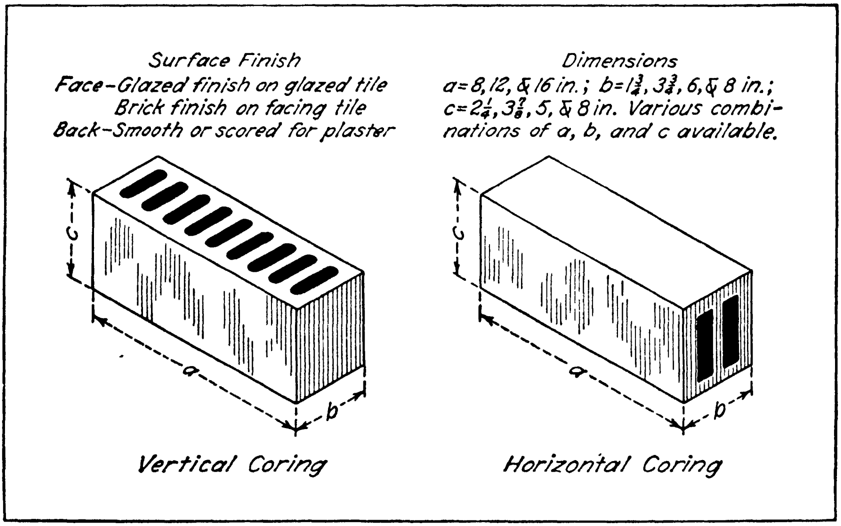


FIG. 83. Clay Glazed and Facing Tile

The required special shapes such as headers, quoins, jambs, sills, lintels, cornices, corners, bullnoses, cores, and caps are furnished for each size of stretchers.

Open spaces inside the tile, called *cells* or *cores*, are formed in the interior of the units by removing a part of the clay by coring, as shown in Fig. 83. This coring may be horizontal or vertical. Structural units may be cored up to 40 per cent of the gross volume, while the coring in heavy-duty units is limited to 25 per cent. There is considerable variation in the form of the cores in the products of different manufacturers.

Hollow-Tile Floor Arches. Floors may consist of arches of specially designed hollow-clay tile supported by steel beams. Hollow-clay tile arches may be flat, as shown in Fig. 84*a*, or segmental, as shown in Fig.

84*b*. The *flat arch* provides a flat surface for the ceiling of the rooms below, and is preferred for that reason; but the *segmental arch* will develop greater strength than the flat arch of the same depth, and is more economical if a flat ceiling is not desired.

The thrust produced by the arches is taken care of by means of steel tie rods passing through the webs of the beams and held in position by nuts at each end. The spacing of the beams supporting tile arches should not exceed 8 ft.

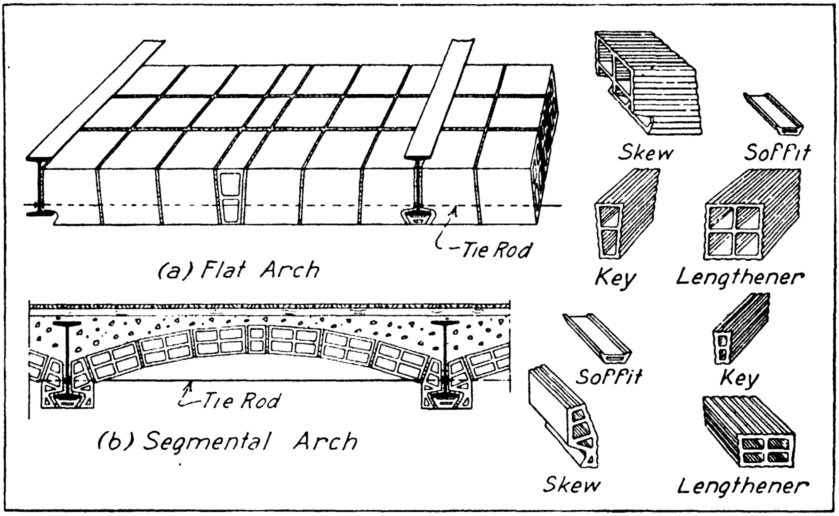


Fig. 84. Hollow-Tile Floor Arches

Hard-burned or semiporous tile are used for floor arches. The thickness of the shells and webs should not be less than $\frac{5}{8}$ in. Every tile should have at least one continuous vertical web for each 4 in. of width. The tile at the ends of the arch and resting against the beams are known as *skewbacks*. These skewbacks should be of such form and section as to fit the beams accurately and to receive the thrust of the arches properly. Care must be used in securing a proper keying or bonding of the various rows of tile, and the tiles should always be set in cement mortar.

The rise of segmental arches should not be less than 1 in. for each foot of span, and the depth should be sufficient to carry the imposed load, but never less than 6 in. with at least 2 cells in this depth.

The depth of flat arches should be at least $1\frac{1}{2}$ in. for each foot of span, not including any portion of the depth of tile that projects below the underside of the beams. The total depth should never be less than 9 in.

The tie rods should be of sufficient size to carry the imposed load, but they should never be less than $\frac{3}{4}$ in. in diameter, and their spacing should not exceed 8 times the depth of the beams which carry the arches, and should not be greater than 8 ft. in any case. They should be completely encased to a depth of 2 in. in fireproofing material extending into and anchored to the arch. Tie rods should be properly located to take the thrust of the arch and in general they should be placed as near the bottom flanges of the beams as practicable.

The lower flanges of beams supporting hollow-tile arches should be fireproofed by lugs which form part of the skewbacks and extend around the flanges meeting at the middle, or by tile slabs held in position by dovetailed lugs projecting from the skewbacks, as shown in Fig. 84*a* and *b*. In either case care should be taken to insure that all joints are solidly filled with mortar. If steel beams or girders project below the ceiling line, they are protected by specially shaped tile.

The space between the tops of the arches and the flooring is filled with cinder concrete consisting of 1 part portland cement to 10 parts of cinders. The cinders must be hard, well-burned, vitreous clinkers, free from sulphide or fine ashes. Cinders from soft coal are likely to be unsatisfactory. Steel or iron pipes or other ferrous metal construction when embedded in cinder-concrete fill should be given a coating of neat cement grout, or be encased in cement or lime mortar as a protection against corrosion. If the finished floor is to be of wood, nailing strips are embedded in the cinder concrete.

Hollow-tile arch floors are light and strong, and were at one time extensively used for steel-framed buildings, but concrete-ribbed slabs are largely used at the present time where tile arches would have been used a few years ago. It is evident that tile arches can not be used advantageously with concrete beams.

Concrete blocks are hollow building units made of portland cement and suitable aggregates such as sand, gravel, crushed stone, cinders, burned clay or shale, and blast-furnace slag. The shell thickness is $\frac{3}{4}$ in. or over. These units are made in a great variety of shapes with thicknesses varying from 2 in. to 12 in., heights commonly about 8 in., and lengths about 16 in. The blocks are made in molds and the concrete is consolidated by tamping or vibrating. A dry mixture is used so that the molds can be removed immediately. The blocks are cured in a moist atmosphere.

Concrete blocks are used for the same purposes as structural clay tile for exterior and interior bearing and non-bearing walls and partitions and for backing up brick, stone, and terra cotta facings. They are extensively used for foundation walls of residences. Careful con-

sideration should be given to protection against termites, as considered in Art. 8, if lumber is to be used in the construction of a building supported on a concrete-block foundation because the tubes which termites form, to maintain connection with the ground, can not be seen if located in the cells. In any case, the tops of the cells of the top layer of blocks in a foundation wall should be closed, as shown in Fig. 9, if a timber sill or plate is to be placed on the wall.

The special surface treatment used on concrete building units to improve their appearance may be divided into the following classes:

a. Special designs with beveled edges, margins or made to resemble some stone finish such as rock face. The imitations of stone finishes are not usually attractive.

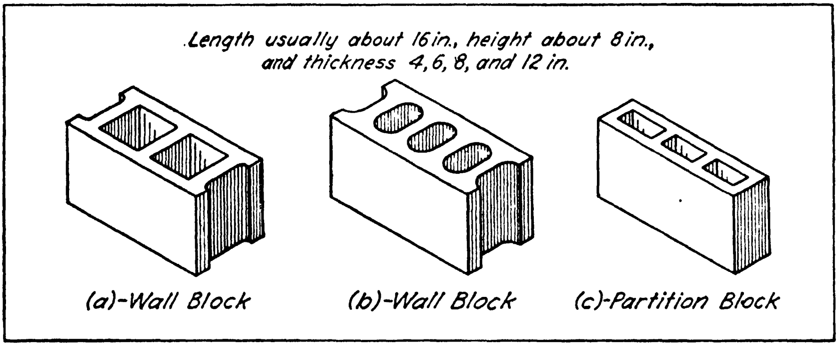


FIG. 85. Concrete Blocks

b. Washes or thin coatings of neat cement or cement paints. These may craze, dust, or change in color if not properly applied or selected.

c. Exposed aggregates obtained by removing the surface film of cement. This may be done by means of a fine spray, supplemented with a brush, before the cement has set appreciably or by using a weak muriatic acid solution if the cement is permitted to harden slightly. If the cement has attained a considerable degree of hardness a wire brush may be used with muriatic acid. For concrete units which have hardened a Carborundum stone or a sand blast may be used.

d. Special aggregates and colors may be used in a facing. Some of the materials used for this purpose are colored marble chips, crushed granite and clay, mica, and even crushed glass. The special aggregates may be exposed, as explained in *c.* The coloring materials are usually mineral pigments. They should not be used in amounts much greater than 10 per cent of the cement on account of the reduction in strength which larger amounts may cause.

Gypsum Tile. These units are made of gypsum with a small amount of wood fiber. They are 12 in. high and 30 in. long and vary in thickness from 2 in. to 8 in. The 2-in. blocks are solid, but the thicker blocks have longitudinal core spaces which may be circular, elliptical, or rectangular in cross-section. The faces of the tile may be scored to receive plaster or smooth for use without plaster in warehouses and in other appropriate locations.

Gypsum tile or block are used for non-bearing partitions, as fire protection for structural-steel members, and for furring outside walls, a special tile being available for that purpose.

Minimum Wall Thickness. The factors which affect the thickness of masonry walls are discussed in Art. 24.

The recommendations of the Building Code Committee of the Department of Commerce for hollow clay tile, concrete block, concrete-tile walls, and hollow walls of brick are as follows:

Lateral Support. Walls of hollow tile or of concrete block or tile, and all hollow walls of brick shall be supported at right angles to the wall face at intervals not exceeding sixteen times the wall thickness in top stories, or eighteen times the wall thickness elsewhere. Such lateral support may be in the form of cross walls, piers, or buttresses when the limiting distance is horizontal, or by floors when the limiting distance is vertical. Sufficient bonding or anchorage shall be provided between the wall and the supports to resist the assumed wind force acting in an outward direction. Piers or buttresses relied upon for lateral support shall have sufficient strength and stability to transmit the wind force, acting in either direction, to the ground. When walls are dependent on floors for their lateral support provision shall be made in the building to transfer to the ground the lateral force resisted by all floors.

Thickness and Height of Exterior Walls Other than in Skeleton Construction. Walls of hollow tile, concrete block or tile, or hollow walls of brick shall not exceed 50 ft. in height above the top of foundation walls.

The thickness of walls of the above materials and types shall be sufficient at all points to keep the stresses due to combined live and dead loads for which the building is designed within the limits prescribed.

The minimum thickness of exterior walls of hollow tile, or concrete block or tile, or of hollow wall construction shall be 12 in. for the uppermost 35 ft. of their height, and at least 16 in. for the remaining lower portion; except that the top story wall of a building not exceeding three stories or 40 ft. in height, or the wall of a one-story commercial or industrial building may be 8 in. thick, provided that the roof beams are horizontal; and except that exterior walls of one and two family dwellings may be 8 in. thick for the uppermost 20 ft. When gable construction is used for such dwellings an additional 5 ft. is permitted to the peak of the gable.

Where walls are stiffened at distances not greater than 12 ft. by cross walls or by internal or external returns at least 2 ft. deep, the thickness may be 12 in.

throughout, except that the top story, or for one and two family dwellings the uppermost 20 ft., may be 8 in. as previously provided.

Bond. Where two or more hollow units are used to make up the thickness of a wall, the inner and outer courses shall be bonded at vertical intervals not exceeding three courses by lapping at least one cell completely over a cell of the unit below.

Beam Supports. Suitable provision shall be made at each line of floor beams in hollow walls or walls of hollow units, to shut off the spaces above from those below, and to ensure good bearing for beams and uniform distribution of loads.

Piers. Hollow tile or hollow concrete block or tile shall not be used for isolated piers unless solidly filled with concrete. The unsupported height of such piers shall not exceed 10 times their least horizontal dimension.

Chases and Recesses. Chases and recesses in walls of hollow tile, hollow concrete block or tile, or in hollow walls of brick shall not exceed in extent those permitted for solid brick walls under the same conditions. Chases and recesses shall not be cut in walls of the above types, but may be built in. No chases or recesses shall be permitted in fire walls that will reduce the thickness below the minimum specified in this code.

Bearing Partitions. When not used as party, fire, or fire division walls, walls of hollow tile, concrete block or concrete tile, or hollow walls of brick shall be not less in thickness than one-eighteenth of the height between floors or floor beams.

Non-Bearing Partitions. Non-bearing partitions of hollow tile, concrete block or concrete tile, hollow walls of brick or of gypsum block or other similar materials shall be built solidly against floor and ceiling construction below and above, and shall not exceed the following unsupported heights:

Thickness Exclusive of Plaster, Inches	Maximum Unsupported Height, Feet	Thickness Exclusive of Plaster, Inches	Maximum Unsupported Height, Feet
2	8	6	20
3	12	8	25
4	15		

Panel and Inclosure Walls. The requirements for hollow tile, concrete-block or tile walls, or hollow walls of brick are the same as for brick walls and are given in Art. 25.

Fire Resistance. For fire-resistive ratings of the types of masonry considered in this article, see Art. 24.

ARTICLE 28. TERRA COTTA

Definitions. *Terra cotta* is an Italian term with a Greek derivation, meaning "burned earth." The term would cover a great variety of

clay products used in building construction, but actually it is used in a restricted sense. Terra cotta building products are often divided into two classes, i.e., *structural terra cotta* and *architectural terra cotta*. According to this classification, structural terra cotta includes such products as hollow clay tile used to construct walls and partitions, where it is serving a structural function, and *architectural terra cotta* used primarily for decorative purposes and for facing walls. The preferred usage is that which has been adopted by the American Society for Testing Materials in " Standard Definitions Relating to Structural Clay Tile," and is as follows:

The term *tile* is understood, within the meaning of these definitions, to mean *structural clay tile*. The term *terra cotta*, which is applied to ornamental building units of burned clay, should not be used to designate structural clay tile.

However, it is difficult to make definite classification. The *facing tile* described in Art. 27 are used for the same purposes as *wall ashlar*, which is considered in this article. Both are hollow units made by extruding plastic clay through dies, but wall ashlar is more accurately finished to size than facing tile and is available in larger sizes. Hand-pressed architectural terra cotta and extruded wall ashlar are included in this article.

Architectural Terra Cotta. Architectural terra cotta is a handmade product used for decorative features of buildings. The clays used in the manufacture of architectural terra cotta are carefully selected to provide the desired physical and chemical properties. As a rule, a mixture of clays is used to secure the proper plasticity and binding qualities before burning to avoid excessive shrinkage and warping while burning and to provide the necessary strength and durability after burning. The chemical reactions which occur during burning affect the color of the product, so must be considered in the selection of clays. The color on the exposed surface is secured by spraying the surface, before burning, with a liquid which has the proper chemical composition, as will be explained in another paragraph.

The architect's drawings must be redrawn and slightly enlarged to allow for a shrinkage of $\frac{3}{4}$ in. to 1 in. per ft. which occurs in burning, to conform to the special requirements of the material and the process of manufacture, and to provide for jointing and anchoring. The drawings thus prepared are called *shop drawings*.

A *model* is made of each piece required, except where several pieces are alike, in which instance one model will serve for the several pieces. In making these models the shop drawings are followed. For plain

work the models are made of plaster of Paris in the plaster shop, but ornamental modeling is done in plastic clay by skilled modelers and sculptors.

Molds are made by surrounding the models with a mixture of plaster of Paris and water. This mixture sets very quickly and the model is removed from the mold, the joints necessary to permit this removal having been provided in the mold.

After the model has been removed the mold is taken to the pressing shop where plastic clay is pressed into the molds by hand to form the terra-cotta blocks. The molds are not filled solid, but the blocks are formed with walls or shells varying in thickness from 1 to 2 in. In order to provide greater strength, webs are put in at intervals to divide the hollow space in the interior of the tile into cells about 6 in. wide. Ordinarily the back of the tile or the side opposite the exposed face is left open, the filling of the mold being accomplished from this side. When sufficiently stiff, the block is turned out on a drying board where it is finished; that is, mold seams are removed and the desired surface texture is provided.

After the blocks are finished, they are taken to drying rooms where the surplus moisture is evaporated, giving the blocks sufficient rigidity to permit handling and placing in the kilns. When the drying process is completed, the terra-cotta blocks pass into the shipping or spraying department where, by means of a compressed-air apparatus, the surfaces which are to be exposed in the building are sprayed with a liquid mixture. During the burning process this mixture develops the desired color or glaze. When the spraying has been completed, the blocks are placed in kilns where they are subjected to a temperature gradually rising to 2000 deg. fahr. or more. The kiln is then slowly cooled to normal. The time required to charge, fire, and discharge a kiln is about two weeks.

The terra-cotta blocks are removed from the kilns and taken to the the fitting floors where they are laid out and fitted together according to the position they are to occupy in the structure. When required, the joints are squared and cut or ground by hand or machine. Blocks which are to be placed in the lower stories of a building where they may be plainly seen must be more carefully fitted than those which are to be placed some distance above the ground where close inspection is not possible. The surfaces forming the joints are shaped to facilitate grinding.

For rail transportation, terra cotta is shipped in bulk, securely packed in hay and braced on the cars to prevent shifting. When it arrives at the building site, the hay is removed and the terra cotta is

placed in piles on wooden strips according to the order required in the building. Each piece is numbered and its position determined by the corresponding number on the erection drawings supplied by the terra cotta manufacturer.

Practically any color can be obtained for the exposed surface of terra cotta. The body of the tile is usually the same for all surface colors, the different colors being obtained by spraying the surface with a suitable liquid mixture, as has already been explained With one burning several different colors can be produced on a single block by applying the proper materials to the surface. For this a brush is used to apply the surface coat instead of the spray, or both may be used. This type of terra cotta is called *polychrome*.

There is practically no limit to the textures and surface treatments which may be obtained with terra cotta. The range extends from the natural clay finish, made impervious by a coating called a *slip*, through matt or dull to lustrous and brilliant glazes; and from a smooth or honed finish, through different degrees of tooling, dragging, and stripping to any degree of roughness desired.

In selecting architectural terra cotta for outside use, care must be taken to obtain a product which will not spall or crack after a few years and whose exposed surface will not craze, crack, or flake off.

Terra cotta should be set with all joints filled solid with portland-cement mortar, consisting of 1 part cement to 3 parts of sand and not more than ½ sack of hydrated lime to each sack of cement.

The backing of terra cotta should proceed simultaneously with the setting of the terra cotta, and at no time should the terra cotta proceed more than one course ahead of brick backing. Each piece of terra cotta should be backed up solid with brick and mortar in order to make a perfect bond and a homogeneous mass between wall lines. This backing will usually extend only to the wall line but should extend beyond the wall line when necessary for structural stability. Concrete is also used for backing.

Joints in terra cotta should be pointed and struck as the setting progresses, except in freezing weather. In freezing weather and when repointing is necessary, all joints should be raked or cut out to a depth of ½ in. and pointed with the same mortar as that used in setting.

Joints in projecting cornices, overhanging terra cotta, balustrades, sill courses, and parapets should be raked out to a depth of ½ in. and be pointed with elastic cement.

Anchoring. Terra cotta may be used as a trim for walls of brick or stone masonry to which it is *anchored* with metal anchors; the entire exposed face may be of terra cotta anchored to a brick backing or

bonded by blocks projecting into the backing; or terra cotta may be anchored to a structural-steel or reinforced-concrete frame. Wherever possible, terra cotta blocks should be so designed that the use of metal anchors can be reduced to a minimum. This can be accomplished by bonding the blocks into the brick backing in a manner similar to that explained in Art. 26 for stone facing. Metal ties, if their use is unavoidable, must be of sufficient strength and also must be effectively protected from corrosion.

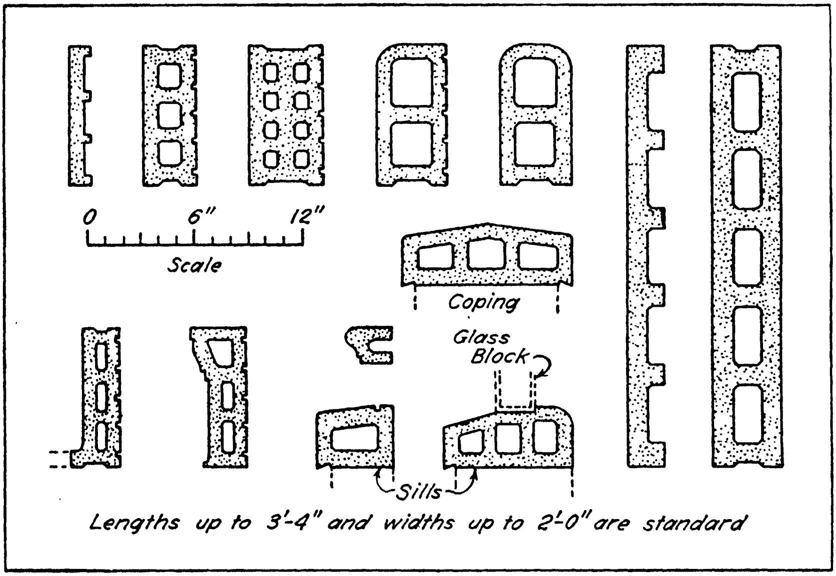


FIG. 86. Terra Cotta Wall Ashlar

Anchors may be made of wrought iron or of steel protected against corrosion by a coating of some kind. The following materials are used for the coating: asphaltum, applied hot; red lead; zinc, applied by the processes of galvanizing and sherardizing; and cadmium, by the Udylite process. The coatings of asphaltum or red lead, and the embedding in mortar, have not given satisfactory protection, but the other processes may be depended upon.

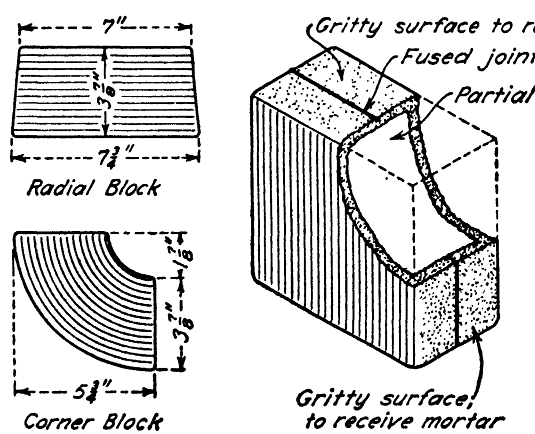
Washes should be provided on all projecting courses and saddles should be provided in ornamental details sufficient to shed water readily. If voids in which water is liable to accumulate remain in the terra cotta after it is backed up and bonded properly and all supporting iron has been encased, then weep holes should be provided at such points as

may be necessary for drainage and air circulation. All projecting courses, such as sills, belts, cornices, and copings, should have drips so that water will not run down the face of the wall.

Wall Ashlar. Wall ashlar is a recent development in architectural terra cotta. It is made by extruding plastic clay through dies as in manufacturing structural clay tile. Standard units are available in various sizes from 8 by 16 in. to 24 by 48 in., with thicknesses of 2, 4, and 6 in. Standard bases, moldings, corners, copings, sills, and other units are manufactured. The units are ground to size and squared to insure uniform joints. The extruded units have solid backs rather than the open backs of the pressed units. Slabs as thin as 1¼ in. are available for use as veneers. Cross-sections of a few typical units are shown in Fig. 86. Structural clay tile facing is manufactured for use as a facing for large flat surfaces in the same manner as wall ashlar. Wall ashlar is more accurately finished to dimensions, and a greater variety of colors and larger sizes are available.

ARTICLE 29. GLASS-BLOCK MASONRY

Glass Blocks. Glass blocks, as shown in Fig. 87, are hollow, colorless, translucent masonry units formed by fusing, at high temperature, two sections which have been cast separately. Their primary function is to transmit light through walls and thereby to replace windows.



Block Sizes	
Length, Inches	Height, Inches
8	4⅞
5¾	5¾
7¾	7¾
11¾	11¾

All Blocks 3⅞ in. Thick

FIG. 87. Glass Blocks

The process of manufacture seals the block and produces a partial vacuum in the interior. Various patterns are available for the exposed faces. The interior or exterior surfaces of each face may be smooth or may have horizontal or vertical ribs or other patterns. If the patterns are on the interior surfaces, the exposed surfaces are smooth. This smoothness permits easy cleaning.

Glass blocks are not suitable for carrying loads other than their own weight. They should be laid in portland-cement-lime mortar. Fine sand should be used and care should be taken to fill all joints completely. If blocks 12 in. high are used, every horizontal joint should be reinforced with strips of galvanized expanded metal $2\frac{1}{2}$ in. wide, or with similar strips, running continuously the full length of the joint if possible; but, where joints in the metal are necessary, there should be a lap of at least 6 in. For blocks 5 and 6 in. high, expanded metal should be placed in every fourth joint and for blocks 8 in. high, in every third joint. The blocks should be shoved in place, compressing the mortar in the vertical joints. After the mortar has obtained its initial set, the joints should be compressed by tooling with a round jointer.

Provision for expansion should be made along the jambs and the head of each panel by setting the edges and top of the panel in chases or recesses $4\frac{1}{4}$ in. wide and $1\frac{3}{4}$ in. deep. Expansion-joint strips $\frac{1}{2}$ in. thick, of cork, fiber glass, or other suitable material should be placed in the recesses or chases for the blocks to bear against and to serve as a seal. Oakum should be rammed into the space between the sides of the blocks and the sides of the chase or recess, leaving $\frac{3}{8}$ in. of depth to be filled with non-hardening waterproof calking. The chases, filled and calked in this manner, serve to resist wind pressure. Provision should be made at the top, where necessary, to allow for the deflection of the lintel so that no load will be thrown on the glass panel.

Panels with an area of more than 144 sq. ft. should be provided with structural stiffening members or else should be subdivided by mullions and shelf angles. Specially designed bronze or aluminum alloy interlocking strips are available for use in interior partitions. The purpose of such strips is to form cellular panels to receive individual glass blocks without mortar and with the edges of the metal exposed. Partitions constructed in this manner are easily moved.

Glass-block panels are used primarily to transmit light where window openings are not required for ventilation or where clear glass is not needed for visibilty. Glass-block panels diffuse the light which passes through them, have a good heat-insulating value, reduce condensation, are reasonably soundproof, and are attractive in appearance. They

are used in exterior walls and interior partitions but can not be used to carry any load other than their own weight. Glass blocks are not laid with the vertical joints broken or staggered as in other masonry, but the vertical as well as the horizontal joints are continuous. See Fig. 224.

ARTICLE 30. CONCRETE MASONRY

Uses. Concrete has largely replaced stone and brick for foundation walls, for it is usually cheaper than brick or stone masonry, and more substantial and water-tight than either. However, brick masonry will stand uneven settlement, without serious cracking, better than concrete. Bearing walls above ground are not usually constructed of concrete; for there is little if any advantage in cost over brickwork, and concrete is unattractive unless special attention is given to the construction of forms and the placing of the concrete to secure a surface with few defects or few objectionable form marks. During recent years, there has been considerable development in the architectural treatment of concrete.[13] Attractive buildings with concrete exterior walls are being constructed. In some, the exposed surfaces are left as they come from the forms, with very little touching up, while in others special surface treatments are used. See Fig. 197.

When the interior of the building is to be of reinforced-concrete construction the usual practice is to use, except for low buildings, the skeleton type of building with wall columns and beams, and inclosure walls of concrete, brick, or hollow tile. This article will deal only with concrete walls, the other types having been considered in other articles.

Concrete is used to a limited extent in constructing bearing partitions and fire walls but it is not usually suitable for non-bearing partitions on account of its weight, the cost of forms, and the difficulty of installing after the floors are in place. Concrete partitions can not be poured much thinner than 4 in.; therefore other forms of construction, being hollow and in some cases thinner, have a distinct advantage in weight and are at least as satisfactory in other respects, including cost.

Concrete Foundations or Basement Walls. Foundation or exterior basement walls may be of several types. The simplest type is that shown in Fig. 88*a*, which supports the vertical load from walls above and withstands the lateral pressure of the earth. Ordinarily the earth pressure is not considered in this type of construction because its effect is small compared with that of the vertical loads, but for low buildings with deep basements the earth pressure may be an important factor in design. Walls of this type are frequently constructed without reinforcement except that in the footings, but longitudinal reinforcement

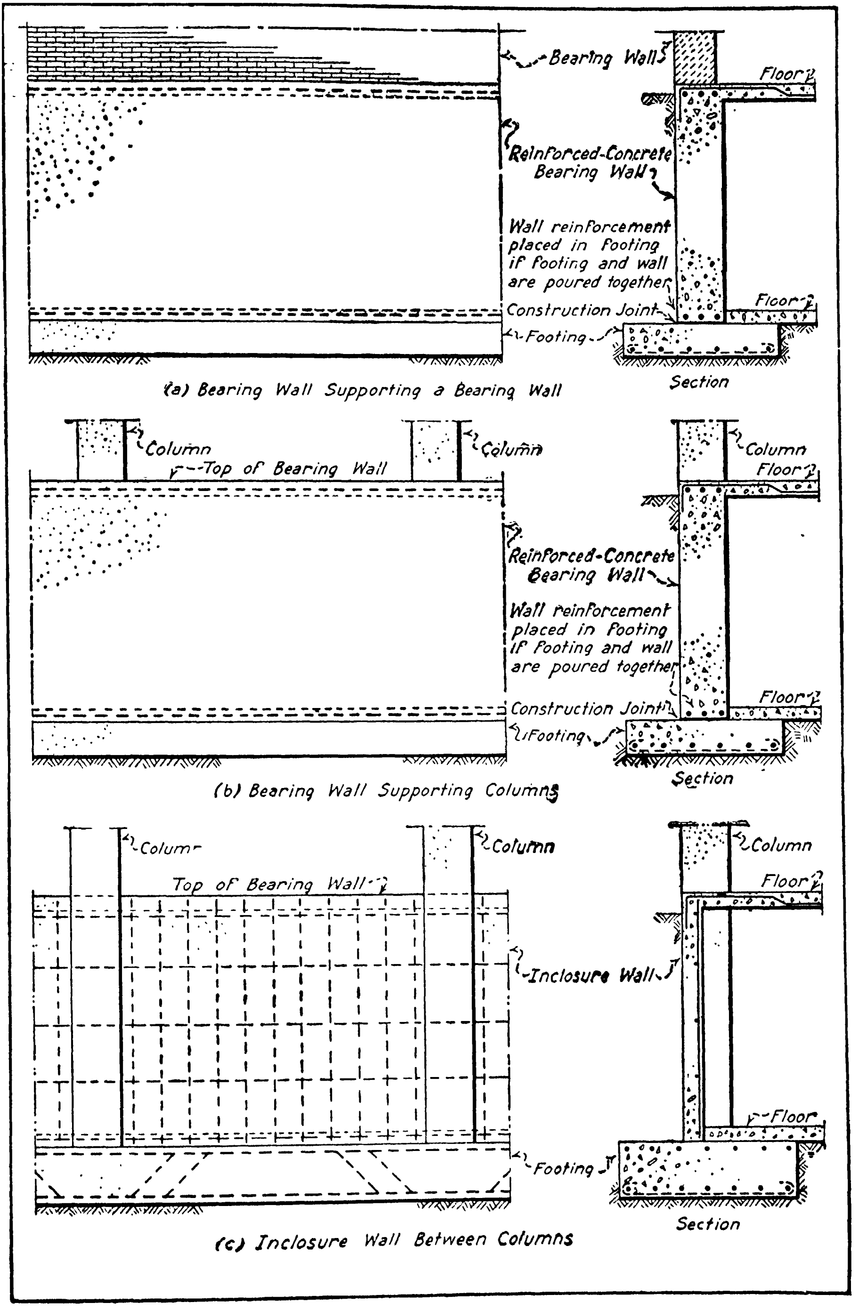


FIG. 88. Reinforced-Concrete Foundation Walls

is desirable to reduce the danger of objectionable cracking due to temperature changes, shrinkage, and uneven settlement. This reinforcement is placed near the top of the wall and near the bottom, just above the footings. Longitudinal reinforcement placed in the footings is not effective in the beam action of the wall because of the construction joint which always exists between the footing and the wall. If special provision needs to be made for earth pressure, the wall may be made thicker than would otherwise be necessary or steel reinforcement may be placed vertically near the inner surface of the wall so that the wall will act as a vertical slab supported at the bottom by the basement floor and at the top by the first floor.

The type shown in Fig. 88*b* is designed to carry the concentrated loads of columns instead of the uniform load of a wall as in the case just discussed. Since there is now a definite beam action, the wall must be designed as a continuous reinforced-concrete beam. The effect of earth pressure and the provisions for such pressure are the same as in the walls of the first type.

Instead of resting the columns on a bearing wall, they may be carried down to a continuous footing, as shown in Fig. 88*c*. The walls are now required to carry only the lateral earth pressure and possibly a load contributed by the first floor. The lateral earth pressure may be provided for by reinforcing the wall as a vertical slab supported by the basement floor and by the first floor, as shown in the figure, or the main reinforcement may be placed horizontally, the necessary support being provided by the columns.

In Fig. 89*a* the columns are carried on independent footings and the wall carries only the lateral earth pressure and possibly a load contributed by the first floor. In this case, the wall is designed as a vertical slab supported at the top by the first floor and at the bottom by the basement floor, the main reinforcement being placed vertically and near the inner face. In Fig. 89*b* the wall is considered as supported by the columns and the main reinforcement is placed horizontally near the inner face. Windows or other openings in the wall will determine the most desirable method of support or, in some cases, it may be economical to design the wall as a slab supported on four sides.

The use of caisson cofferdams for the basement walls of larger buildings is described in Art. 21, and illustrated in Fig. 55.

Plain and Reinforced-Concrete Walls. All walls constructed of concrete should contain some reinforcement to provide against cracks due to temperature changes or unequal settlement. Building codes divide concrete walls into two classes: plain and reinforced. Walls which have less than $\frac{2}{10}$ of 1 per cent of reinforcement are classed as

plain concrete walls whereas those with that amount or more are classed as *reinforced-concrete walls.*

Plain Concrete Walls above Ground. Bearing and non-bearing walls above ground may be constructed of plain concrete without steel reinforcement, but to avoid cracks due to settlement and changes of tem-

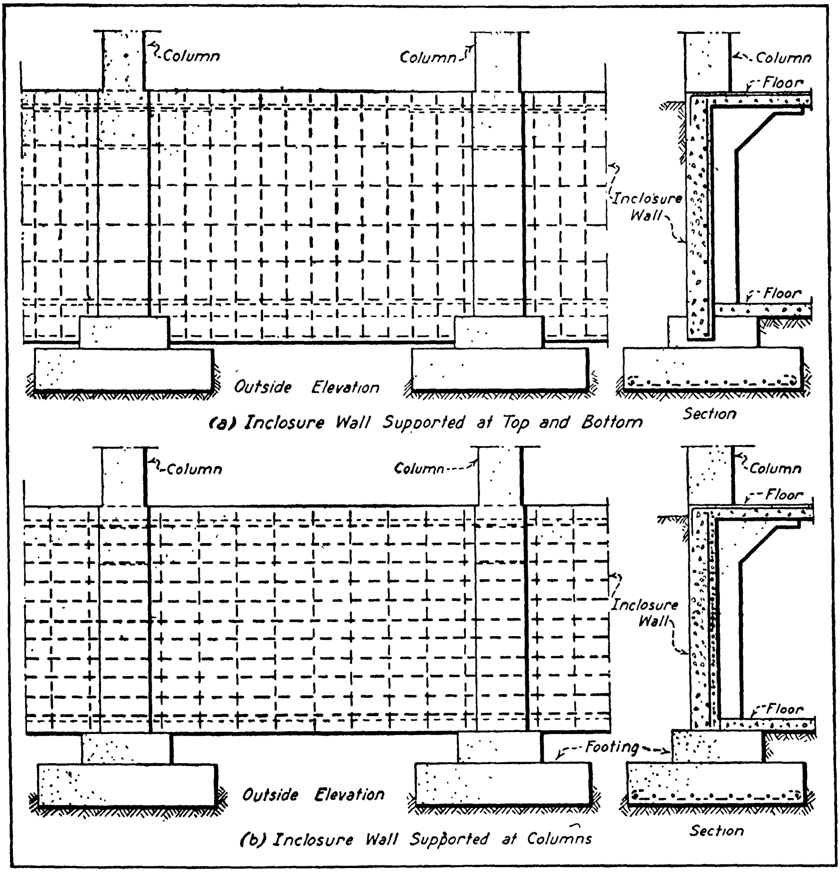


FIG. 89. Reinforced-Concrete Foundation Walls

perature it is desirable to use some reinforcement, particularly at corners and around openings. Horizontal reinforcement is much more essential than vertical reinforcement. In exterior walls classed as plain concrete, it is frequently desirable to place a band consisting of one or two bars all around the building just above the window openings and another band just below these openings. It is also desirable to place a similar band of steel near the top of the wall. Diagonal

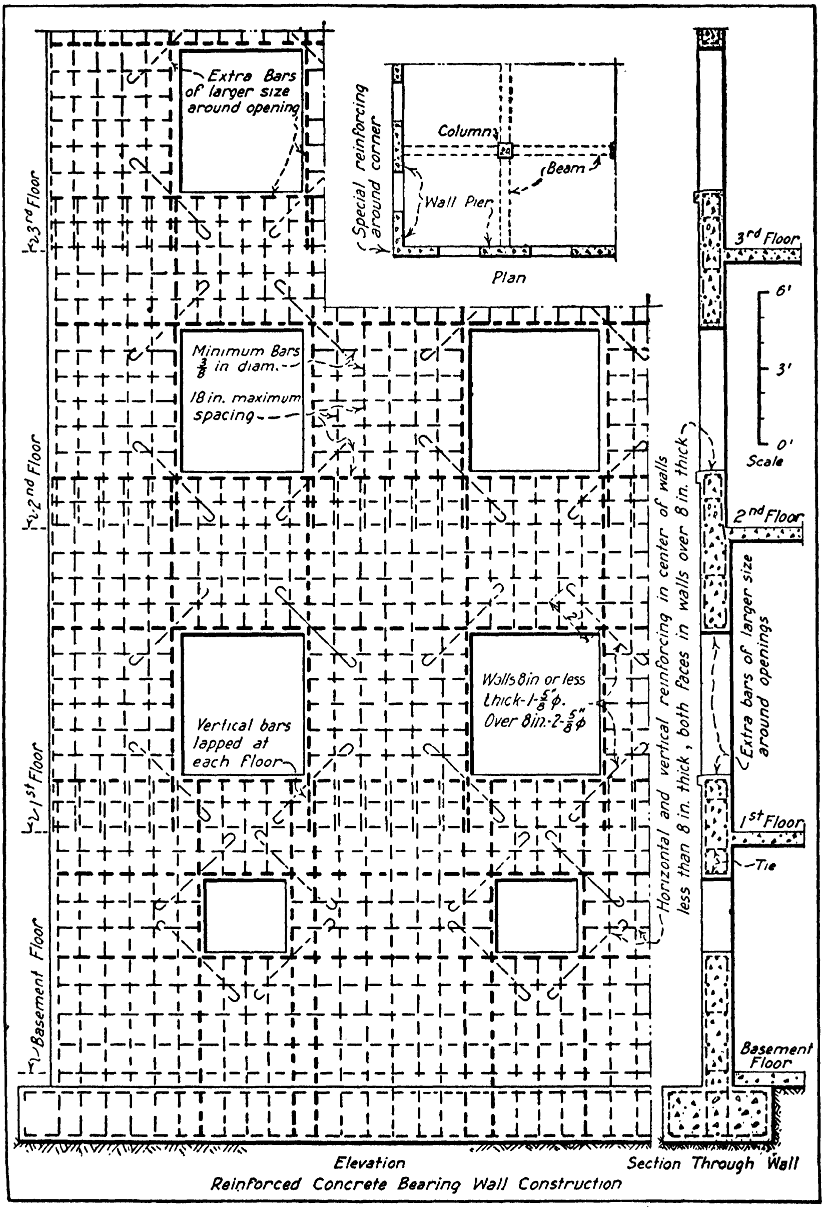
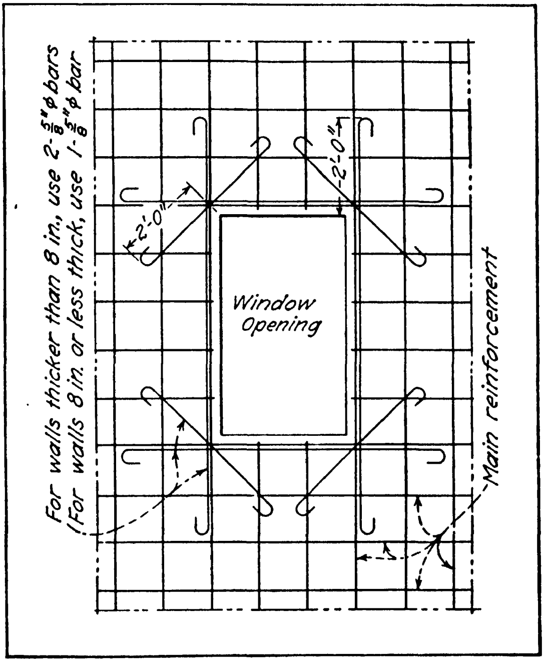


FIG. 90. Reinforced-Concrete Bearing Walls

bars at the corners of openings, as shown in Figs. 90 and 91, are effective in preventing cracks, and vertical bars at the sides used in connection with horizontal bars above and below the openings are desirable.



Portland Cement Association

FIG. 91. Reinforcement around Wall Openings

The Building Code Committee of the Department of Commerce makes the following comments concerning hollow walls of plain concrete:[1]

Several systems of construction are used which produce hollow or double walls of plain concrete. Usually there are two shells, each 3 or 4 in. thick, with an air space between. The inner and outer parts of such walls generally are tied together with wires or metal strips sufficient for stability in small dwellings; but, if the area of both walls is needed for compressive strength and stability, positive means is required to bring them into common action. Unless some device or method adequate to do this is provided, the use of such walls for commercial structures over 2 stories in height or residences more than 3 stories is not advocated.

It is recognized that a hollow wall of plain concrete having the same net cross-sectional area as one of concrete block would be somewhat thicker. It may be said, however, that concrete block are better controlled as to quality, and their action under load is better known at this time than that of hollow concrete walls.

Reinforced-Concrete Walls above Ground. Reinforced concrete is extensively used for panel walls in skeleton construction and to a lesser degree for bearing and non-bearing walls. Those walls should be reinforced with small steel bars placed horizontally and vertically and spaced from 8 to 12 in. apart, as shown in Fig. 90. Additional reinforcement should be placed around all openings and at points of concentrated loading, as shown in Fig. 91.[16] The reinforcement around openings should preferably be made continuous in both directions. The piers between openings should be provided with ties perpendicular to the face of the wall. Reinforced-concrete bearing walls have been used up to 10 stories in height for buildings with an interior framing of reinforced concrete.[14]

In skeleton construction the exterior walls rest on wall beams and are carried by the structural frame. They are called *panel walls* and are usually installed after the structural frame is completed.

Panel walls are required to carry only the wind pressure; so their thickness is usually determined by the minimum thickness which can be poured and which will be water-tight. The thickness should never be less than 4 in. and will rarely be over 12 in. Inclosure walls should be reinforced with wire fabric or small rods placed 12 to 18 in. apart, running horizontally and vertically. They are not always tied to the structural frame but may be held in place by fitting into channels left in the columns. A weather-tight joint between the column and the wall is secured by a metal diaphragm or by other methods. A turned-up spandrel beam may serve as a panel wall.

Partitions. Concrete is not used extensively in constructing partitions, other types having been found to be more suitable. When concrete partitions are used, they should be at least 3 in. thick and should be reinforced both horizontally and vertically with light steel rods or wire fabric.

Surface Finishes. The following material is taken from the Report of the Joint Committee on Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete.[15]

General. (*a*) Surface finish is a term used to denote the process or method of mixing, placing, and treating concrete to produce a desired appearance and texture of the surface.

(*b*) The requirements of the sections of the report relating to materials, forms, mixing, curing, conveying, depositing, and protection of concrete should apply, except as they may be modified by these special requirements.

(*c*) Concrete should be placed in one continuous operation between prescribed expansion or construction joints, unless the drawings indicate other points where the placing of concrete can be discontinued.

(*d*) The same brand of cement, the same kind and size of aggregates, the same proportions and type of finish should be used where it is desired to duplicate texture and appearance on any showing surface.

Forms. (*a*) Forms for finished surfaces should be smooth and mortar-tight. If wood forms are used, the boards must be uniform in thickness, tongued-and-grooved, smoothly finished on the surface next to the concrete, evenly matched and tightly placed, except where the desired surface or appearance requires special treatment.

(*b*) The forms should be so constructed as to be removable in sections without marring or damaging the surface of the concrete. Forms should be removed as soon as possible in order to make necessary repairs and finish the surface. As soon as forms are removed, any undesired fins or other projections on the surface should be carefully removed, offsets leveled, and voids or damaged places immediately saturated with water and repaired by filling with a concrete or mortar of the same composition as was used in the surface. After the necessary repairs are made, the surface should be finished with a wood float so as to be free from streaks, discolorations, or other imperfections. Plastering should not be permitted and a steel trowel should not be used to finish surfaces.

Preparation for Surface Finish. (*a*) Where a surface mortar is to be the basis of the finish, the coarse aggregate should be worked back from the forms with a suitable tool so as to bring a full surface of mortar against the forms, care being taken to prevent the formation of voids and aggregate pockets.

(*b*) Where a special surface finish is called for on the drawings or in the specifications, the work of preparation should be carried out as specified.

Decorative Surface Finishes. The following material is taken from the Report of the Joint Committee.[15]

General. (*a*) Modern materials and methods may be used in the decorative treatment of architectural concrete to express the designer's ideas and taste in a wide variety of motifs, color, and texture.

(*b*) Decorative finishes on exposed concrete surfaces may be classified as:

1. Precast ornament.
2. Monolithic ornament.
3. Surface treatment after removal of forms.
4. Applied finish.

Precast Ornament. Precast ornamental units should be applied to the inside face of forms or set in framed openings in the structural form work. Such units are ordinarily made of cast stone from ap-

proved models. Positive anchorage into concrete should be made by means of rabbets, lugs, non-corrodible metal anchors, or other approved means of anchorage.

Monolithic Ornament. (*a*) Ornament is produced monolithically by forming concrete with negative models or molds. The precast models or stamped forms should be accurately and securely set in the structural forms. Special treatment of absorptive molds should be provided to prevent the absorption of moisture. Particular care is required in the design of the mixtures and in placing ornamental concrete to assure structural soundness and the desired finish.

(*b*) Finished samples of positive models should be submitted and approved as to craftsmanship, form, texture, and appearance.

(*c*) Construction joints in monolithic ornament, when necessary, should be located and constructed in such a manner as to be unobjectionable in the finished work. When molds are removed in less than 7 days, the surface should be immediately sprinkled with water and kept wet until the concrete is at least 7 days old. All ornamental work should be protected from damage until it is accepted.

Surface Treatment after Removal of Forms. (*a*) The desired appearance, texture, and finish for the surface should be determined from sample surfaces. Form linings, such as sheet metal, fiber, or manufactured board, may be used to produce concrete surfaces with specified markings or patterns.

(*b*) Where special facing mix with selected aggregates is to be used, it should be placed to the required thickness and in such a manner as to bond securely with the backup concrete.

(*c*) The time removal of face forms will depend upon the type of surface finish desired. For scrubbed finish the face forms should be removed as soon as safety permits and before the surface becomes too hard. For rubbed, sandblasted, or tooled finishes, the surface must be thoroughly cured and hard before finishing.

Type of Finish. (*a*) Rubbed finish. The surface should be thoroughly wetted, and rubbed or ground with Carborundum or another abrasive until it presents a uniform and smooth appearance. Cement mortar may be used in the rubbing, but the surface should not be brush-coated with cement or grout after rubbing.

(*b*) Scrubbed finish. The surface should be thoroughly wetted and scrubbed with stiff fiber or wire brushes, water being used freely until the surface film of mortar is removed and the aggregate uniformly exposed. The surface should then be rinsed with clean water. If portions of the surface have become too hard to scrub in equal relief, dilute hydrochloric acid (commercial acid diluted with 4 to 10 parts

water may be used to facilitate the scrubbing), the acid being removed from the finished surface with clean water.

(*c*) Sandblasted finish. The thoroughly cured concrete surface should be sandblasted with hard sharp sand until the aggregate is in uniform relief.

(*d*) Tooled finish. The thoroughly cured concrete surface should be dressed with tools to a uniform texture and even face. The tools ordinarily used are electric or air or hand tools, giving various textured surfaces, such as hand-tooled, rough or fine-pointed, crandalled, or bush-hammered, as specified and as selected from sample surfaces.

(*e*) Sandfloated finish. The forms should be removed before the surface has fully hardened. The surface should be wetted and rubbed with a wood float by a uniform circular motion, fine sand being rubbed into the surface until the resulting finish is even and uniform.

Applied Finish. (*a*) With applied stucco or plaster finishes, the surface of the concrete should be removed to a depth of at least $\frac{1}{16}$ in., exposing the aggregate and leaving a clean firm granular surface for the permanent adhesion of the finish. A chemical compound may be used on the inside of forms to retard the setting of the surface concrete, in which case all loose material should be removed and surface thoroughly cleaned before finishing. If mechanical treatment, such as hacking or chipping or grinding is used, care should be taken to leave no untreated surfaces. A mechanical bonding surface may be formed by using a suitable form material or form lining.

(*b*) When the first coat of stucco or plaster is applied, the concrete should be thoroughly wetted but should have no free water on the surface.

Minimum Thickness and Reinforcement. The minimum thickness and the amount of reinforcement required for reinforced-concrete walls by the Building Regulations for Reinforced Concrete of the American Concrete Institute, 1936, are, in part, as follows:

a. (Devoted to working stresses and omitted here.)

b. Walls shall be designed for any lateral or other pressure to which they are subjected. Proper provision shall be made for eccentric loads and wind stresses.

c. Panel and inclosure walls of reinforced concrete shall have a thickness of not less than 5 in. and not less than $\frac{1}{30}$ the distance between the supporting or inclosing members.

d. Bearing walls of reinforced concrete in buildings of fire-resistive construction shall be not less than 6 in. in thickness for the uppermost 15 ft. of their height; and, for each successive 25 ft. downward, or fraction thereof, the minimum thickness shall be increased 1 in.

e. In buildings of non-fire-resistive construction, bearing walls of reinforced concrete shall not be less than $1\frac{1}{3}$ times the thickness required for buildings of fire-resistive construction, except that, for dwellings of 2 stories or less in height, the thickness of walls may be the same as specified for buildings of fire-resistive construction.

f. Exterior basement walls, foundation walls, fire walls, and party walls shall be not less than 8 in. thick.

g. Reinforced-concrete bearing walls shall have a thickness of at least $\frac{1}{25}$ the unsupported height or width, whichever is the shorter; provided, however, that approved buttresses, built-in columns, or piers designed to carry all the vertical loads may be used in lieu of increased thickness.

h. Monolithic walls shall be anchored to the floors, columns, pilasters, buttresses, and intersecting walls with reinforcement at least equivalent to $\frac{3}{8}$ in. round bars 18 in. on centers, for each layer of wall reinforcement.

i. Monolithic walls shall be reinforced with an area of steel in each direction, both vertical and horizontal, at least equal to 0.0025 times the cross-sectional area of the wall, if of bars, and 0.0018 times the area, if of electrically welded wire fabric. The wire of the welded fabric shall be of not less than No. 10 W. & M. gauge. Walls more than 8 in. in thickness shall have the reinforcement for each direction placed in two layers parallel with the faces of the wall. One layer consisting of not less than $\frac{1}{2}$ and not more than $\frac{2}{3}$ the total required shall be placed not less than 2 in. nor more than $\frac{1}{3}$ the thickness of the wall from the exterior surface. The other layer, comprising the balance of the required reinforcement, shall be placed not less than $\frac{3}{4}$ in. and not more than $\frac{1}{3}$ the thickness of the wall from the interior surface. Bars, if used, shall not be less than the equivalent of $\frac{3}{8}$ in. round bars, nor shall they be spaced more than 18 in. on centers. Welded wire reinforcement for walls shall be in flat-sheet form.

Reinforcement in accordance with the following table is recommended by the Portland Cement Association:[16]

WALL REINFORCEMENT

(Outside Reinforcement To Be at least 2 in. from Face, and Inside at least 1 in.)

Wall Thickness	Horizontal Reinforcement	Vertical Reinforcement
6 in.	$\frac{3}{8}$ in. round, 8-in. centers in outside face of wall	$\frac{3}{8}$ in. round, 8-in. centers in outside face of wall
8 in.	$\frac{3}{8}$ in. round, 6-in. centers in outside face of wall	$\frac{3}{8}$ in. round, 8-in. centers in outside face of wall
10 in.	$\frac{3}{8}$ in. round, 10-in. centers in both faces of wall	$\frac{3}{8}$ in. round, 12-in. centers in both faces of wall
12 in.	$\frac{3}{8}$ in. round, 8-in. centers in both faces of wall	$\frac{3}{8}$ in. round, 12-in. centers in both faces of wall

Additional reinforcement is recommended around the openings, as shown in Fig. 91. The regular bars along the edges of the opening continue through, but in the figure they are masked by the lines showing the additional bars.

Fire Resistance. For fire-resistance ratings of concrete walls see Art. 24.

REFERENCES

1. Building Code Committee: "Recommended Minimum Requirements for Masonry Wall Construction," Department of Commerce, 1925. Modifications of the above, 1931 and 1939.

2. National Board of Fire Underwriters: "Building Code," 1934.

3. FISHBURN, CYRUS C., and DOUGLAS E. PARSONS: "Water Permeability of Masonry Walls," Building Materials and Structures Report BMS7, National Bureau of Standards, 1938.

4. HANSEN, J. H.: "Making Dampproof Brick Walls," Technical Bulletin 8, Brick Manufacturers' Association of New York.

5. PLUMMER, HARRY C., and LESLIE J. REARDON: "Brick Engineering," Structural Clay Products Institute, 1939.

6. Brick Manufacturers Association of New York: "Cavity Walls," Technical Bulletin 10.

7. FITZMAURICE, R.: "Principles of Modern Building — Walls, Partitions and Chimneys," Vol. 1, London, His Majesty's Stationery Office, 1939.

8. Building Code Committee: "Recommended Minimum Requirements for Fire Resistance in Buildings," Department of Commerce, 1931.

9. BOWLES, OLIVER: "The Stone Industries," McGraw-Hill Book Co., 1939.

10. KESSLER, D. W., and W. H. SLIGH: "Physical Properties of Principal Limestones Used for Building Construction in the United States," Technologic Paper 349, Bureau of Standards.

11. MERRILL, G. P.: "Stones for Building and Decoration," John Wiley & Sons, 1910. (Out of print.)

12. Federal Board for Vocational Education: "The Setting of Cut-Stone Trim," Bulletin 106.

13. HART, W. D.: "Reinforced Concrete Walls for Buildings," *Proceedings of the American Concrete Institute*, Vol. XXIV.

14. SPITZER, FELIX H.: "Bearing Walls Eliminate Columns in Apartment Buildings," *Engineering News-Record*, Vol. 101.

15. "Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete," Report of the Joint Committee of the American Concrete Institute, American Institute of Architects, American Railway Engineering Association, American Society of Civil Engineers, American Society for Testing Materials and the Portland Cement Association, June, 1940.

16. Portland Cement Association. "Concrete for Industrial Buildings and Garages."

17. TREGONING, S. S.; MILLIKEN, K. A.; HOCKMAN, A.; SLIGH, W. H., and KESSLER, D. W.: "Plastic Calking Materials," Building Materials and Structures Report BMS33, National Bureau of Standards, 1940.

18. HANSEN, J. H.: "Design and Construction Data, Brick Cavity Walls, New York City Building Code Requirements," Technical Bulletin 14, Brick Manufacturers Association of New York.

19. Pacific Coast Building Officials Conference: "Uniform Building Code," 1940.

CHAPTER V

THE STRUCTURAL ELEMENTS

ARTICLE 31. INTRODUCTION AND GENERAL DISCUSSION

The structure of all buildings is made up of various combinations and forms of walls, columns, ties, beams, trusses, rigid frames, and arches. These may be classed as the *structural elements*.

Walls are usually constructed of some form of masonry as described in Chapter IV, or of wood as in frame construction, or of corrugated steel sheets as used on some types of mill buildings.

Columns and beams may be constructed of wood, steel, or reinforced concrete. Cast iron was extensively used at one time for columns and for short beams such as lintels, but steel and reinforced concrete have largely taken its place. Wrought iron has been entirely replaced by steel as a structural material.

Trusses are usually constructed of steel, but wood is used quite extensively and reinforced concrete occasionally. Reinforced concrete is not usually considered an appropriate material for truss construction although there are many examples of its successful use where local conditions have led to its selection.

Rigid frames are constructed of wood, reinforced concrete, and steel. Arches of long span are usually constructed of wood, steel, and reinforced concrete. Arches over openings in walls are usually constructed of brick or stone, as described in Arts. 24, 25, and 26.

The assembling of the various structural elements so that each may perform its functions is known as *framing*. One classification of buildings is on the basis of the function of the walls. If the walls carry their share of the dead, live, and other loads, in addition to keeping out the weather, etc., the building is classed as *wall-bearing construction;* but, if the loads, including the weight of the walls, are carried by the structural frame consisting of columns, beams, trusses, rigid frames and arches, the building is classed as *skeleton construction*, as explained in Art. 2. This term is usually used only for buildings of the office building type and not for the mill building type.

Frame construction with structural elements consisting of light wood joist and studs is extensively used in dwelling-house construction, but is not used for larger buildings.

Ordinary construction is similar to frame construction but has exterior walls of masonry. It is extensively used for dwelling-house construction, but its chief field is for apartment house, stores, and industrial buildings of various types which require a better class of construction than frame construction but which do not need to be slow-burning or fireproof.

Slow-burning construction consisting of heavy timber beams, girders, columns, floors, and roofs with masonry walls is extensively used for manufacturing plants and industrial buildings requiring a substantial form of construction which will offer considerable resistance to fire.

Steel construction consisting of steel beams, girders, columns, and trusses supporting floors and roofs of light joist construction, of heavy timber construction, or of fireproof construction is extensively used on all classes of buildings except dwelling houses. The exterior walls may be bearing walls for the lower buildings, but for buildings of more than 3 or 4 stories skeleton construction is usually used. In the better class of buildings fire-resistive construction is used throughout. For buildings up to 15 or 20 stories high, steel and reinforced-concreted construction are on a competitive basis; but, for higher buildings, steel construction is without a rival. Great speed is possible with steel construction. In some cases, the structural frame and floor slabs have been constructed at the rate of a story a day after the foundations are in place. Skyscrapers are completed in a year.

Reinforced-concrete construction may be used for nearly all classes of buildings where good construction is essential. Dwelling houses are rarely of this type, but apartment houses, hotels, office buildings, school houses, warehouses, and industrial buildings are commonly built of reinforced concrete. In buildings with a steel framework, the floors and roofs are often of reinforced concrete. For tall buildings steel construction has the advantage on account of the smaller size of the columns for the lower floors. This advantage has resulted in the limiting of concrete buildings to 15 or 20 stories. In some cases, the columns of the lower stories are made of steel and those above of concrete. For buildings 3 or 4 stories in height, exterior bearing walls may be used, but above that height skeleton construction is usually adopted. Even for the lower buildings, skeleton construction may be used on account of the greater speed of construction which is possible with this type. When bearing walls are used, each floor must wait until the bearing wall can be built up to carry it; whereas with skeleton construction the structural frame and floor slabs may be constructed as rapidly as a story every two days after the foundations are in place.

ARTICLE 32. COLUMNS AND OTHER COMPRESSION MEMBERS

Forces which tend to shorten or compress a member are called *compressive forces,* and the stresses set up in a member by these forces are called *compressive stresses. Bending* or *flexural stresses* are set up in a member when it is bent.

The vertical members of a structural frame are called columns. They are called upon to transfer the floor and roof loads to the foundations. Such loads cause stresses in the columns which are chiefly compressive but on account of eccentric loads, rigidity of joints, and wind loads, columns are also subjected to bending stresses which may be of considerable magnitude.

Classes of Columns. Columns may be divided into three general classes according to the ratio of the longitudinal dimension to the lateral dimension.

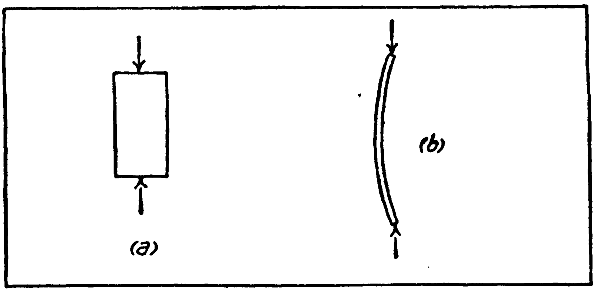


FIG. 92. Classes of Columns

If the length of a column is relatively small when compared with its width, as shown in Fig. 92*a,* the column does not tend to bend to any extent, when carrying a load; and, if the load is applied so that its center of gravity is on the axis of the column, the stresses will be uniformly distributed over each cross-section of the column. If the length of a column is great when compared with its width, the column will tend to fail by bending or buckling, as shown in Fig. 92*b,* when carrying a load, the magnitude of the compressive stress being small. A third class would include those columns intermediate in ratio of length to width to the classes just mentioned; such columns tend to fail by a combination of direct stress and bending or buckling. Reinforced-concrete columns are usually of the first class; timber and steel columns may be in either the first or third class. Columns of the second class are not used to any extent.

Other Terms Used. Columns are often called *posts,* especially when made of timber. Truss members carrying compressive stresses are

called *struts,* but their action is the same as that of columns. In general, members which carry compressive stresses are called *columns, posts, struts,* or *props.*

The light, closely spaced, vertical, compressive members used in frame construction are called *studs.* Relatively slender blocks or prisms of masonry carrying compressive stresses are called *piers.* Stone or brick columns are sometimes called *pillars,* but this is not a technical term. The term pier has about the same meaning as pillar and is more commonly used. In England, the term *stanchion* is used in place of the term column as used in this country.

Materials. Columns are usually made of timber, steel, reinforced concrete, or cast iron, but stone columns are frequently used for ornamental purposes.

ARTICLE 33. BEAMS AND GIRDERS

A *beam* may be defined as a member supported at one or more points along its length and designed to carry loads acting perpendicular to its length, the reactions at the supports being parallel to the direction of the loads, as shown in Fig. 93*a*.

If the line of action of the loads is not perpendicular to the length of the beam, these loads may be resolved into components acting perpendicular to the length of the beam and components acting parallel to the length of the beam, as shown in Fig. 93*b*. In carrying the transverse components, the beam is performing its primary function; while in carrying the components parallel to its length, it is acting as a column.

A beam may be curved or bent, as shown in Fig. 93*c*, if the supports are so arranged that the reactions at the supports will be vertical for vertical loads. This may be accomplished by placing one end on rollers, as shown in Fig. 93*c*, or, to a certain degree, by using plates which permit sliding. If the ends are so arranged that horizontal movement is restricted as the structure deforms, the reaction will no longer be vertical and the structure will be an arch, as shown in Fig. 93*d*.

Flexural Stresses. There are two general classes of stresses set up in a beam by the loads, i.e., flexural or bending stresses, and shearing stresses. The material on the upper side of the beam shown in Fig. 93*a* is compressed or shortened and that on the lower side is lengthened. The stresses causing the shortening are called *compressive stresses,* and those causing the lengthening are called *tensile stresses.* Taken together they are called *flexural stresses.* These stresses are greatest at the top and at the bottom of the beam and are zero at the *neutral axis* near the center of the depth, the exact location of the neutral axis depending upon the shape of the section. For a beam composed of one material,

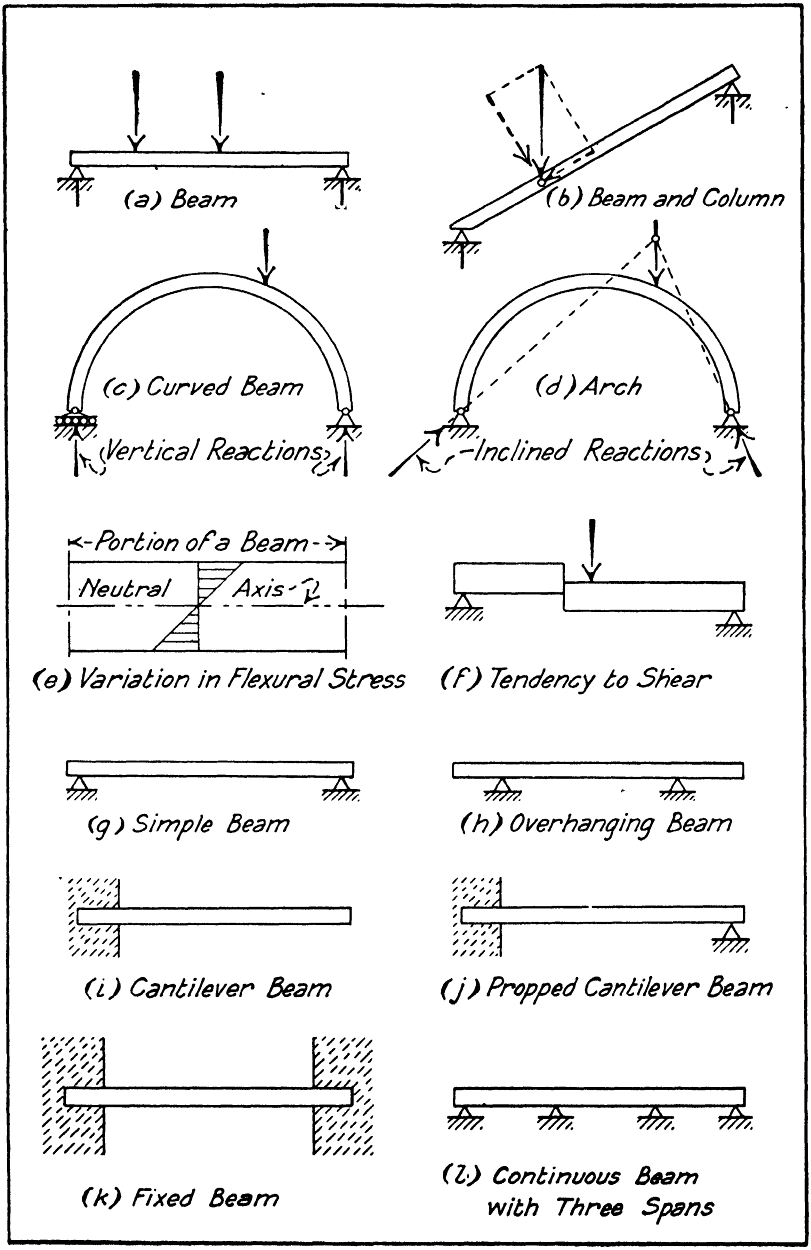


FIG. 93. Types of Beams

the neutral axis passes through the centroid of the transverse section. The variation of stress may be illustrated by the triangles in Fig. 93*e*, the intensity of stress usually varying directly as the distance from the neutral axis, as indicated by the lengths of the horizontal lines in the triangles.

Shearing Stresses. It is evident that the forces acting on a beam tend to cut it along vertical sections, as shown in Fig. 93*f*. The stresses set up in the beam by this action are called *shearing stresses*.

Classification According to Method of Support. Beams may be divided into the following classes according to method of support:

Simple beam. A simple beam is supported at two points near its ends, as shown in Fig. 93*g*.

Overhanging beam. An overhanging beam is supported at two points but projects beyond or overhangs one or both supports, as shown in Fig. 93*h*. It is a special case of the simple beam.

Cantilever beam. A cantilever beam is supported at one end only but it is rigidly held in position at that end as shown in Fig. 93*i*.

Propped cantilever. A propped cantilever beam is supported at two points and is rigidly held in position at one of them, as shown in Fig. 93*j*.

Fixed beam. A fixed beam is supported at two points and is rigidly held in position at both points as shown in Fig. 93*k*.

Continuous beam. A continuous beam is supported at three or more points as shown in Fig. 93*l*.

Classification According to Use. Beams may be classified according to use as follows:

Beam. When any distinction is made between beams and girders, the beam is the smaller member and may be supported by the girder.

Girder. See discussion above for Beam.

Lintel. A beam supporting the masonry and other loads over an opening in a wall. See Fig. 225.

Joists. Closely spaced beams supporting a floor or ceiling. See Figs. 134 and 135.

Rafters. Closely spaced beams supporting the roof and running parallel to the slope of the roof. See Figs. 134, 135, and 208.

Hip rafter. The member running along the hip of a framed hip roof and having the ends of the jack rafters fastened to it. See Figs. 133 and 208*a*.

Valley rafter. The member running along the valley of a framed roof and having the ends of the jack rafters fastened to it. See Fig. 208*a*.

Jack rafter. Any short rafter, but usually a rafter running between the wall plate and the hip rafter and called a *hip jack*, or between the valley rafter and the ridge and called a *valley jack*. See Fig. 208*a*.

Purlin. A beam resting on the top chords of roof trusses or girders and supporting the rafters or other roof construction. See Fig. 208*b* and *c*.

Girt. A beam placed horizontally on the sides of a building and fastened to the columns. See Fig. 166*a*.

Header. A beam which carries the ends of beams which are cut off in framing around an opening, as shown in Fig. 94.

Tail beam. A beam which frames into a header instead of spanning the entire distance between supports. See Fig. 94.

Trimmer. A beam at the side of an opening and carrying one end of a header, as shown in Fig. 94.

Collar beam. A horizontal member running between two rafters on opposite sides of a framed roof and usually, but not necessarily, located at some

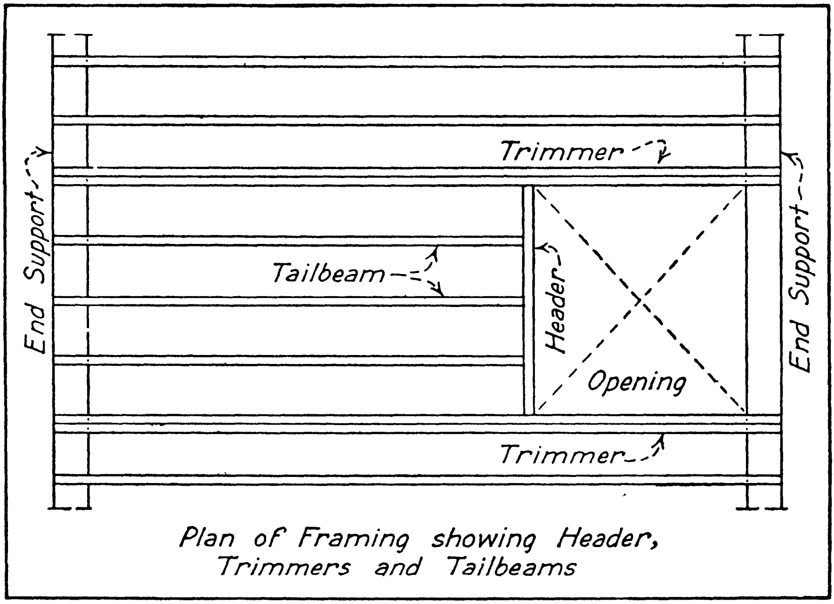


FIG. 94. Headers, Trimmers, and Tailbeams

distance above the wall plates. See Fig. 135. A collar beam does not necessarily act as a beam. It may act as a tie if the rafters are not so anchored as to prevent the spreading of the lower ends, but if they are securely held at that point the collar beam acts as a strut which reduces the deflection in the rafters.

Materials. Beams may be constructed of wood, steel, or reinforced concrete, as described in the following articles. Cast iron was quite extensively used a number of years ago and stone is occasionally used for lintels but, owing to their low flexural strength, stone lintels are usually supported by steel lintels which do not show on the face of a building.

ARTICLE 34. TRUSSES

A *truss* is a framed structure consisting of a group of triangles arranged in a single plane in such a manner that loads applied at the points of intersection of the members will cause only *direct stresses* (tension or compression) in the members. The framework shown in Fig. 95*a* will illustrate the essential features of a truss, although a truss of this type is of no practical use.

To be classed as a truss the ends of a framework must be supported in such a manner that the reactions at the supports are vertical for vertical loads. This result is accomplished by arranging one end so that horizontal movement may take place by sliding or rolling on the bearing plate, as shown in Fig. 95*b*, when loads are applied, or when changes of length due to temperature changes occur.

If the ends are so arranged that horizontal movement is restricted, the reactions will be inclined and the framework will act as an *arch*, as shown in Fig. 95*c*. It is not customary to provide sliding or rolling bearings for trusses whose span does not exceed 40 or 50 ft.

Parts of Truss. The points of intersection of the members of a truss are called *joints* or, in some cases, *panel points*. The upper line of members forms the *upper* or *top chord;* and the lower line, the *lower* or *bottom chord*. The members connecting the joints on the upper chord to those on the lower chord are the *web members*. See Fig. 95*a*. Web members carrying compressive stresses are *struts*, and those carrying tensile stresses are *ties*. The terms *end post*, *vertical post*, *hip vertical*, and *panel* apply to special forms of trusses and will be defined later. See Fig. 95*k*. The distance center to center of supports is called the *span*.

Materials. Trusses may be built wholly of wood, of wood and steel rods combined, or of rolled-steel sections. Concrete is used to a limited extent but is not usually a suitable material for trusses. Cast iron and wrought iron have been used in the past but these materials are not used at the present time.

Types of Trusses. Considering that a truss is composed of a group of triangles, it is evidently possible to arrange innumerable types; but certain types have proved to be more satisfactory than others and each of these types has its special uses. The various types of trusses used in building construction are illustrated by line diagrams in Fig. 95*d* to Fig. 96*n*. The members indicated by heavy lines normally carry compressive stresses and those indicated by light lines normally carry tensile stresses, for vertical loads. The types shown with parallel chords may have their top chords made sloping slightly in one or two directions, for roof drainage, without changing the type. The number of subdivisions

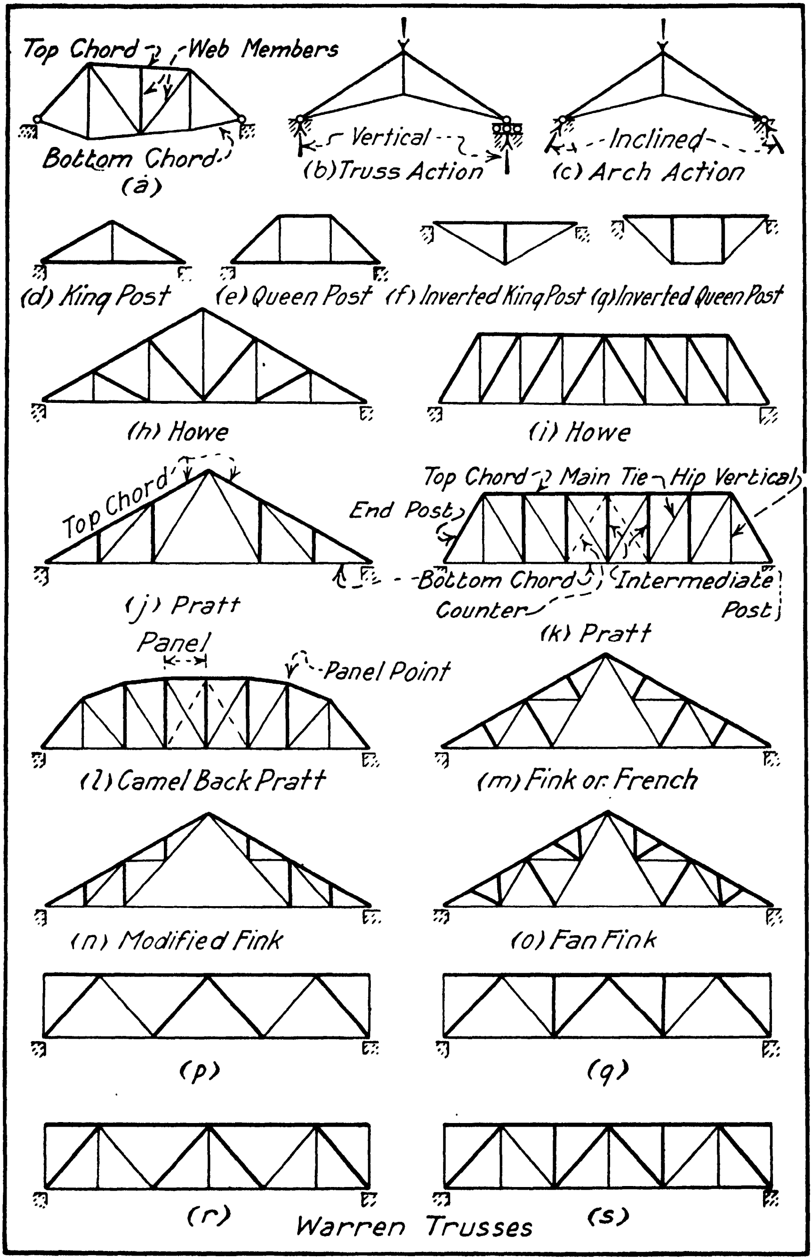


FIG. 95. Types of Trusses

or panels will depend upon the length of span and the type of construction.

The more common forms of trusses will be discussed in the following paragraphs.

The *king-post truss* shown in Fig. 95*d*, the *queen-post truss* shown in Fig. 95*e*, and the *inverted king-post* and *queen-post trusses* shown in Figs. 95*f* and 95*g* are all used for short spans in connection with wood construction. The members indicated by heavy lines are made of wood, and those by light lines are usually steel rods. The inverted king-post and queen-post trusses are often called *trussed beams* and are described in Art. 39. The lower chords of the trusses in Figs. 95*d* and 95*e* carry tensile stresses but are usually made of wood and therefore are indicated by heavy lines.

The *Howe truss* may be constructed with inclined top chords, as shown in Fig. 95*h*, or with parallel chords, as shown in Fig. 95*i*. Howe trusses are always constructed with the members indicated by heavy lines made of wood. Those indicated by the light lines may be steel rods. The truss with sloping chords is commonly used for pitched roofs, whereas the truss with parallel chords may be used to support flat roofs or floors. Howe trusses may be divided into any number of panels to suit any span or purlin spacing.

The *Pratt truss* may be constructed with inclined top chords, as shown in Fig. 95*j*; with parallel chords, as shown in Fig. 95*k*; or with broken upper chord, as shown in Fig. 95*l*, forming a *camel-back Pratt truss*. Pratt trusses are constructed of wood or steel sections. The truss with sloping chords is used for supporting sloping roofs and the type with parallel chords may be used for supporting flat roofs or floors. Pratt trusses may be divided into any number of panels to suit any span or purlin spacing.

The *Fink truss* is always constructed with inclined chords, as shown in Fig. 95*m*, and all the members are made of steel sections or of wood. Fink trusses are very widely used in supporting sloping roofs. They may be divided into any number of panels to suit any span or purlin spacing. A modified form of Fink truss is shown in Fig. 95*n*, and a *fan Fink* or *fan truss* in Fig. 95*o*.

The *Warren truss* is always constructed with parallel chords, as shown in Fig. 95*p*. Vertical members may be provided to reduce the distance between joints on the upper chord, as shown in Fig. 95*q*; on the lower chord, as shown in Fig. 95*r*; or on both chords, as shown in Fig. 95*s*. The Warren truss is very widely used for supporting floors or flat roofs. The *bowstring truss*, shown in Fig. 96*a*, is usually constructed of wood.

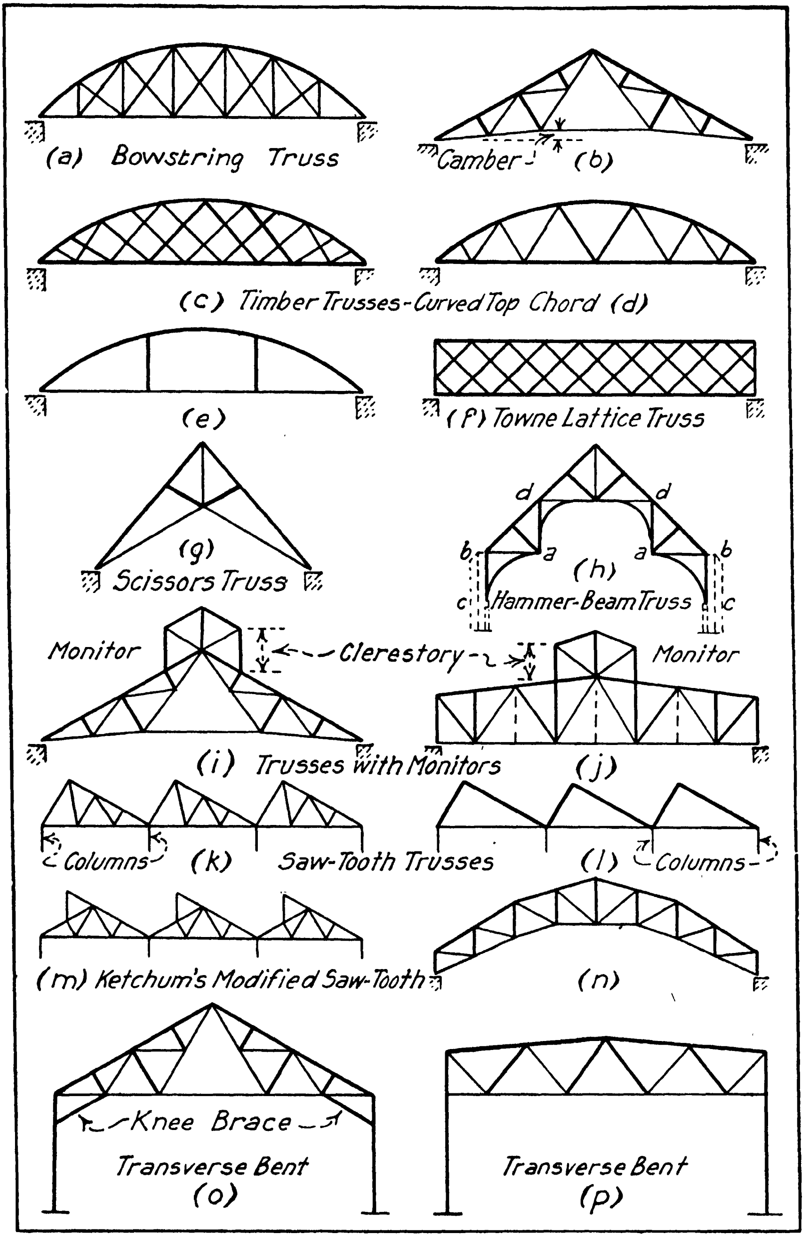


FIG. 96. Types of Trusses and Transverse Bents

A truss is said to be *cambered* when the bottom chord is raised at the center, as in the cambered Fink truss shown in Fig. 96*b*. Camber improves the appearance of a truss and avoids sagging and the illusion of sagging.

Various special forms of wood roof trusses are shown in Fig. 96*c* to *h*. The trusses shown in Fig. 96*c* and *d* have curved upper chords, the various members being built up of 1-in. or 2-in. lumber. A curved trussed beam is shown in Fig. 96*e*. This beam is built up of light lumber and steel rods. A *scissors truss* is shown in Fig. 96*g*, a *hammer-beam truss* in Fig. 96*h*, and a *Towne lattice truss* in Fig. 96*f*. In the hammer-beam truss shown in Fig. 96*h* the parts of the truss marked *a–b–c* act as brackets to reduce the span to *d–d*. These brackets must be securely fastened to the wall along the vertical member *b–c* and the wall must be capable of withstanding the outward thrust produced at the point *c*. The structural action is quite complicated.

Other special forms of roof trusses are shown in Fig. 96*i* to *n*. *Monitors* are placed on top of roof trusses as shown in Fig. 96*i* and *j* to give better light and ventilation, the vertical face of a monitor, called the *clerestory*, being provided with glass in sash which will open to provide light and ventilation, or with *louvres* for ventilation only. See also Fig. 207*d* and *e*.

The *saw-tooth trusses* shown in Fig. 96*k* and *l* are used to provide light and ventilation, the steeper face of the roof being covered with glass arranged so that a part of the sash will open. This face is usually turned toward the north to secure a uniform light. The type shown in Fig. 96*k* is constructed of steel, and that in Fig. 96*l* is constructed of timber and steel rods. See also Fig. 207*b*.

Another form of saw-tooth truss is shown in Fig. 96*m*. In this type the vertical face is provided with top-hung sash. This type is always constructed of steel sections. See also Fig. 207*c*.

A camel-back Pratt truss with cambered lower chord is shown in Fig. 96*n*.

Steel or timber roof trusses may be secured to columns in such a way as to give lateral rigidity as shown in Fig. 96*o* and *p*. Such combinations of trusses and columns are called *transverse bents*. In the transverse bent shown in Fig. 96*o* the braces between the truss and columns are called *knee braces*. They are provided to give transverse or lateral rigidity.

A type of truss which is rarely used is the *Vierendeel truss*, illustrated in Fig. 97. It does not satisfy the definition of a truss but is given that designation. Trusses of this type are advantageous for use where it is

necessary to keep unobstructed openings between the vertical posts, as in the floating foundation described in Art. 15. In such foundations they are built of reinforced concrete, but elsewhere steel is also used.

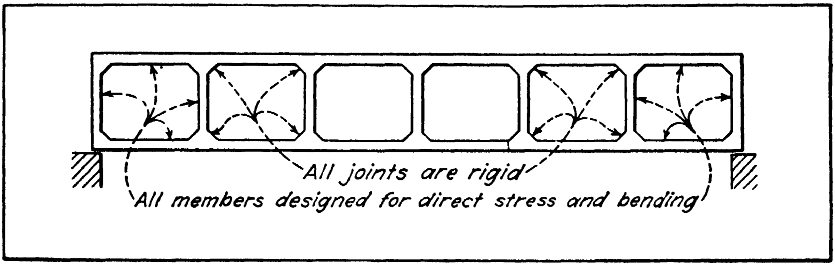


FIG. 97. Vierendeel Truss or Girder

Because of the omission of diagonals, all the members are subjected to bending stresses and the joints must be rigid to make the structure stable.

ARTICLE 35. ARCHES AND RIGID FRAMES

The use of brick and stone arches in building construction has been discussed in Chapter IV. These arches have a structural function but their design is determined largely by appearance.

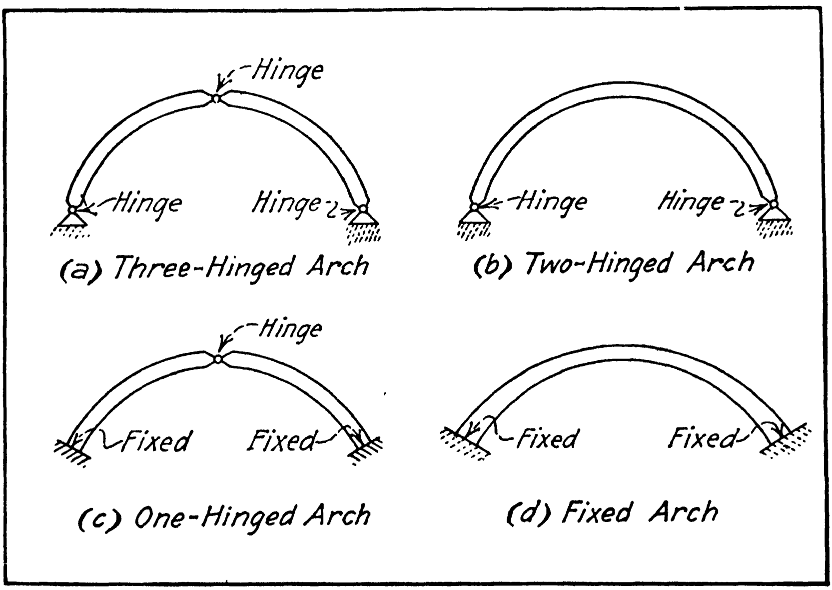


FIG. 98. Types of Arches

Arches whose primary function is structural are constructed of wood, steel, and reinforced concrete. They are used chiefly for the support of roofs covering large areas such as required in auditoriums, armories, exhibition buildings, field houses for athletics, gymnasiums, dance halls, hangars, and garages.

Arches may be *ribbed arches* with arch rings which are subjected to compressive and flexural stresses, or they may be built up of triangular elements in the same manner as trusses and then are called *framed arches*. The members of framed arches carry tensile or compressive

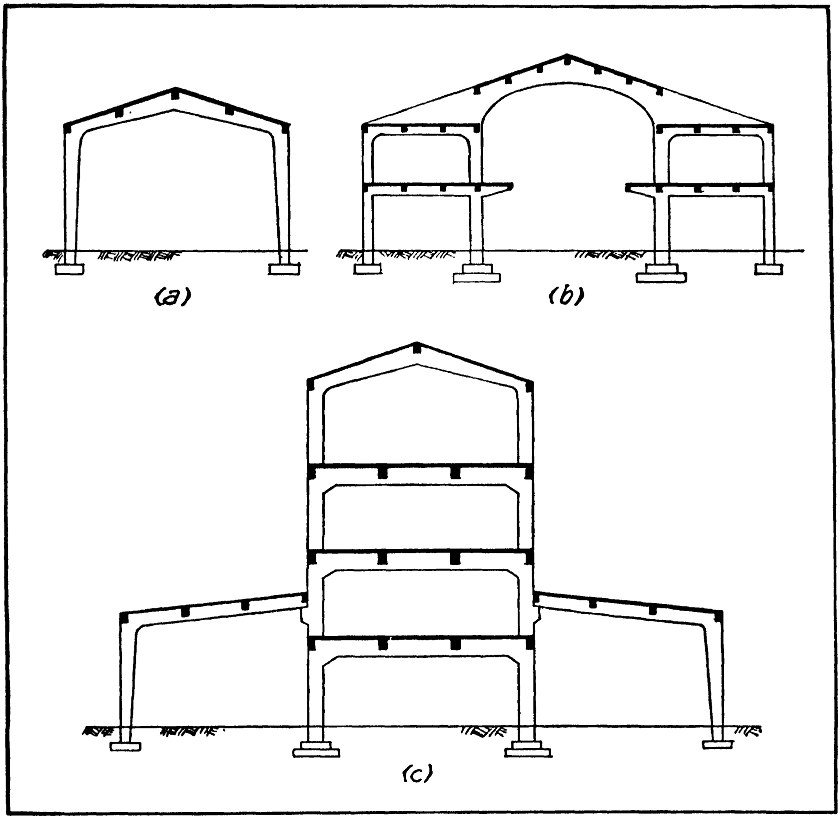


Fig. 99. Reinforced-Concrete Rigid Frames

stresses but not bending stresses. Reinforced-concrete arches are always of the ribbed type with solid or hollow arch rings. Steel arches and wood arches may be of either type.

Arches may be constructed with the ends of the arch ring securely anchored to the abutments, or hinges which permit rotation may be

introduced at these points or at the crown. In the *three-hinged arch* there is a hinge at each abutment and one at the crown, as shown in Fig. 98*a*; in the *two-hinged arch* there is a hinge at each abutment as shown in Fig. 98*b*; in the *one-hinged arch* there is a hinge at the crown but the ends of the arch ring are securely fixed at the abutments as shown in Fig. 98*c*; and in the *no-hinged* or *fixed arch* no hinges are provided and the ends of the arch ring are rigidly anchored to the abutments as shown in Fig. 98*d*. Steel and wood arches are usually of the three-hinged or two-hinged type. Reinforced-concrete arches may be of the three-hinged, two-hinged, or fixed types. The one-hinged arch is rarely used.

Rigid frames are rapidly coming into use. The wind bents of tall steel buildings and the unit formed by the columns and girders in a

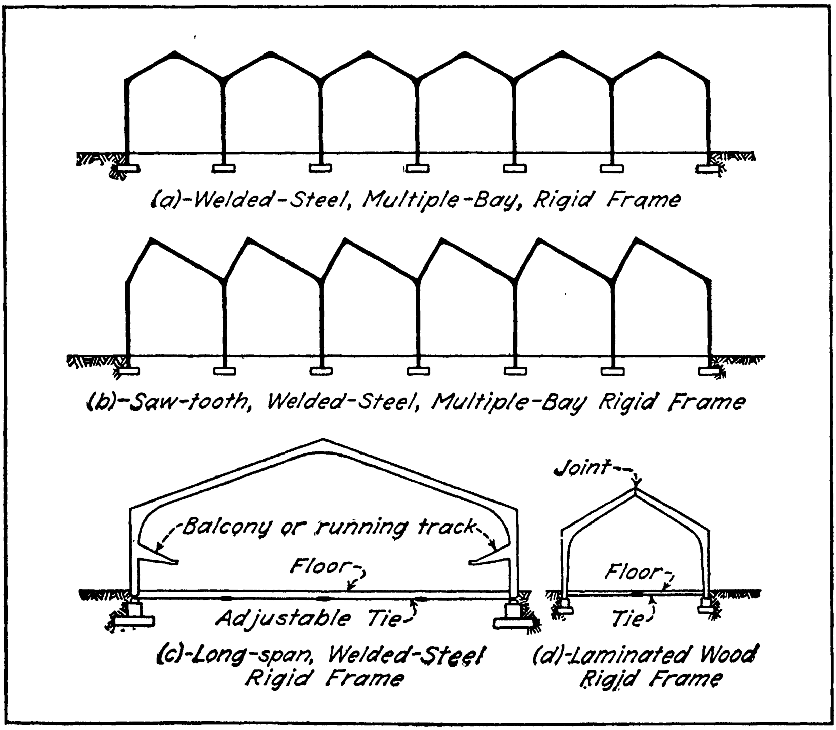


FIG. 100. Steel and Wood Rigid Frames

reinforced-concrete frame are complex rigid frames although they are not usually classed as such. The most common type of rigid frame consists of a roof girder or arch rigidly connected to the columns at its

ends so that the three elements act together in resisting vertical and lateral loads, the horizontal reaction of the arch and the deflection of the girder causing bending in the columns.

Rigid frames may be of many types, some of which are illustrated in Figs. 99 and 100. The simple rigid frame, such as shown in Fig. 99*a* and Fig. 100*c*, resembles a two-hinged arch and is often called an arch but is preferably classed as a rigid frame. In general, it may be said that arches are so proportioned as to keep the flexural stresses, in the frame as a whole, quite low; whereas, in rigid frames, the flexural stresses are relatively high. Both the inner and outer parts of an arch would normally be in compression, but tension exists in many parts of a rigid frame. The frames illustrated in Fig. 96*o* and *p* are called *transverse bents,* as explained in the preceding article, but they might also be called rigid frames. They are quite similar in their structural action to the rigid frame shown in Fig. 99*a*.

With the development of welding and flame-cutting procedures, described in Art. 48, the use of steel rigid frames is increasing rapidly. Several types are illustrated in Fig. 100. Coming into use are wooden rigid frames made of laminated members consisting of boards bent to the required curvature and glued together. Plywood also offers opportunities for rigid-frame construction.

CHAPTER VI

WOOD CONSTRUCTION

ARTICLE 36. CONNECTING DEVICES

General Discussion. This chapter is concerned with building construction which is primarily of wood. Various terms such as lumber, wood, wooden, frame, and timber are applied to parts of a building constructed of wood. The basic material is always wood just as steel and concrete are basic materials. According to the definition in the American Lumber Standards, given in Art. 8, *timber* is lumber 5 in. or larger in least dimension and *lumber* is the product of the saw and planing mill. In general, the term timber is used to designate heavy wood members or construction, while frame is usually applied to light wood construction. There is a tendency toward a more extensive use of the term wood in place of the term timber. It is difficult, and probably not worthwhile, to attempt to be entirely consistent in the use of the terms wood and timber.

This article will consider various methods used in holding the wood parts of a building together. All of the devices considered are not used in framing a structure, but many are included which are used on such parts as interior finish. For instance, large nails and spikes are used in framing but finish nails are not. However, it is convenient to consider finish nails in this article.

Nails. Nails commonly used in building construction may be divided into two general classes, *wire nails* and *cut nails.* The size of nails is designated thus, 8d or 16d, called 8 penny or 16 penny. This method of designation originated in the cost per 100 nails, but no longer has this significance.

Wire nails are formed from steel wire of the same diameter as the nails. The common forms of wire nails are shown in Fig. 101*a* to *c*. Common nails are used where there is no objection to the exposed head and where the wide head is desirable, as in framing, sheathing, subfloors, etc.

Casing nails are used principally with matched flooring, ceiling, and drop siding. *Finish nails* are used with interior and exterior finish, the heads being sunk below the surface with a *nail set* and the hole thus formed being filled with putty to conceal the nails. Common nails vary

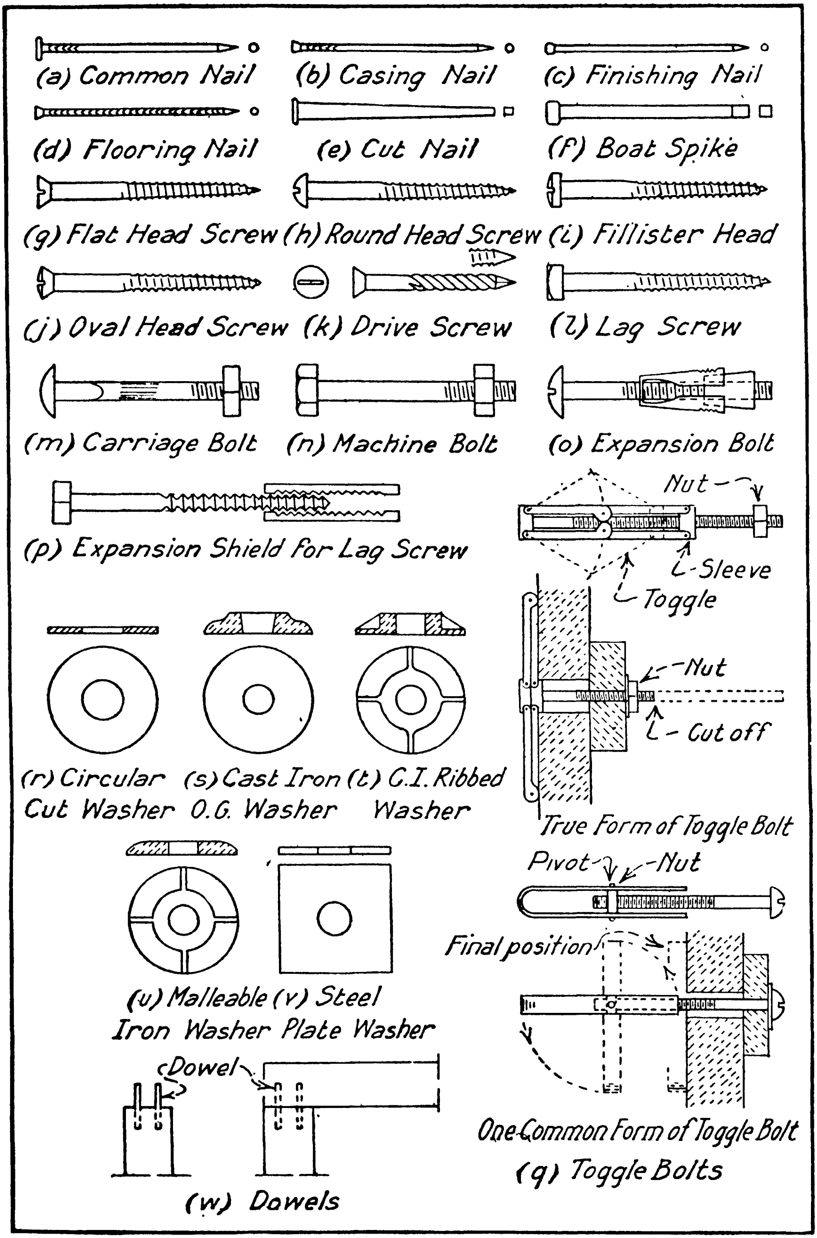


FIG. 101. Nails, Screws, Bolts, Washers, and Dowels

in size from 2d, with a length of 1 in., to 60d, with a length of 6 in.; casing nails from 2d, with a length of 1 in., to 40d, with a length of 5 in.; and finish nails from 2d, with a length of 1 in., to 20d, with a length of 4 in.; the diameter varying with the length. A *barbed flooring nail* is illustrated in Fig. 101*d*. *Shingle* and *lath nails* are small nails of the same shape as common nails. *Wire spikes* are the same general shape as common nails, but they may have diamond or chisel points and flat or convex heads. Their size is designated by the length in inches and varies from 6 in. to 12 in. Wire nails, plain or galvanized, with large heads, are made for use with prepared roofing; galvanized and zinc-coated wire and copper nails are made for tile and slate roofing; and cement-coated nails are made for use where resistance to withdrawal is an important factor. Various other types of wire nails are on the market and galvanized common nails are available in many sizes.

Cut nails and *spikes,* as shown in Fig. 101*e,* are stamped out of steel plates of the same thickness as the nail. Various sizes and shapes are manufactured to correspond with wire nails and spikes.

The initial holding power of cut nails is greater than that of wire nails, but the holding power when partly withdrawn is less. Wire nails are more easily driven than cut nails. Cut nails have a greater length of life when exposed than wire nails. Wire nails are much more widely used than cut nails.

Boat spikes are made of square bars of steel or wrought iron. They have a wedge-shaped point and a head as shown in Fig. 101*f*. The size of boat spikes varies from ¼ in. sq. by 3 in. in length to ½ in. sq. by 12 in. in length. Boat spikes are used in heavy timber framing.

Screws. Screws may be divided into two general classes, i.e., wood screws and lag or coach screws.

Wood screws may be made of steel, brass, or bronze. Steel wood screws may have the natural steel finish called bright or they may be blued, chromium- or nickel-plated, bronzed, lacquered, or galvanized. Various forms of wood screws are shown in Fig. 101*g* to *k*. They all have the slotted head so that they may be driven with a screwdriver, and with the exception of the *drive screw* they have gimlet points. Drive screws have diamond-shaped points and steep-pitched threads so that they may be driven with a hammer. The size of wood screws is designated by the length and gage, several gages being available in each length. Wood screws vary from ¼ in. to 6 in. in length. They have a great variety of uses in building construction.

Lag screws have a conical point and a square head. *Coach screws* have a gimlet point and a square head, as shown in Fig. 101*l*, but both forms are commonly called lag screws. The size of lag and coach screws

is designated by the diameter and length of the shank, both being expressed in inches. The lengths vary from 1¼ in. to 12 in., and the diameters from ¼ in. to 1 in. Lag screws are used for heavy timber framing.

A hole should usually be bored for screws to avoid splitting and to make driving easier. This hole should be somewhat smaller than the diameter at the root of the thread.

Bolts. Bolts used in building construction may be divided into the following classes: carriage bolts, machine bolts, and drift bolts.

Carriage bolts have a round head shaped as shown in Fig. 101*m* and a square nut. The portion of the shank immediately under the head is square and the remainder of the shank is round. The square portion of the shank when embedded in a timber prevents the bolt from turning while the nut is being turned. The size is designated by the length of shank and of the diameter in inches. Carriage bolts may be obtained in almost any size. They are used in bolting pieces of timber together and are used where the square portion of the shank will be embedded in wood. Cut washers are usually used under the head and nut to give greater bearing area.

Machine bolts may have square or hexagonal heads and nuts, as shown in Fig. 101*n*. The shank is round throughout its entire length. The size is designated by the length of shank and the diameter in inches. Machine bolts are available in almost any size. They are used for bolting steel and cast-iron members to timber and for bolting timber or steel members together during erection or permanently, and for use with modern connectors. *Turned bolts* are accurately finished machine bolts.

A *drift bolt* is defined by Jacoby[2] as a piece of round or square iron or steel, with or without head or point, driven as a spike. Drift bolts are used in heavy framing. Before driving, a hole must be bored somewhat smaller than the drift bolt.

Expansion bolts are of many different forms, but in all forms a special nut is used which is so designed that after insertion in a hole the process of turning the bolt will so enlarge or expand the nut that it can not be withdrawn. One form is illustrated in Fig. 101*o*. Expansion shields for use with lag screws, as shown in Fig. 101*p*, are commonly used. Lead expansion shields are available for use with ordinary screws. Expansion bolts are used to fasten wood or iron to masonry which is already in place.

Toggle bolts of various forms are on the market. The head in all bolts is so arranged that, after the bolt has been inserted head first in a hole until the head is free on the other side of the piece, it will rotate or

open up in such a manner that it can not be pulled back through the hole. Two forms of toggle bolt are illustrated in Fig. 101*q*. Toggle bolts are used in places where bolts can not be inserted in the usual way because one face is inaccessible.

Washers. Washers are used under the head and under the nut of a bolt in timber construction to provide a larger bearing area and to prevent the crushing of the wood fibers. Washers are of five types, various sizes being available in each type to suit the various sizes of bolts. These types may be listed as follows: *circular cut washers*, as shown in Fig. 101*r*; *cast-iron O. G. washers*, as shown in Fig. 101*s*, the name being derived from the O. G. curve of the sides; *cast-iron ribbed washers*, as shown in Fig. 101*t*; *malleable iron washers*, as shown in Fig. 101*u*; and *steel plate washers*, as shown in Fig. 101*v*, which are made special to suit each case.

Dowels. *Dowels* are steel or wooden pins extending into, but not through, two members of a structure to connect them, as shown in Fig. 101*w*. A *tree-nail* is similar to a wood dowel, but it is used in such a manner that one or both ends are exposed.

Modern Connectors. Various types of metal connectors designed to connect individual pieces of wood have come into use in this country during recent years. They are called *modern connectors* and consist of metal rings, plates, and disks embedded in the contact surfaces of two members, as shown in Fig. 102*a* to *e*. They are embedded in such a manner as to prevent sliding and thereby to make possible the transmission of stress across the surface from member to member. Joints that make use of these connectors are much more effective than any type previously available; moreover, they have greatly extended the possibilities of timber construction for trusses, arches, and other structures.

A large number of types have been devised but only a few are used to any extent in this country.[1,3,4] The more common types are illustrated in Fig. 102. All require bolts passing through the centers of the connectors to hold the timbers in contact and, with some connectors, to use in forcing the connectors into the timbers. Special tools are available for preparing the timbers to receive the connectors, for connectors requiring such preparation, and for pulling the timbers together after the connectors are in position.

The *split-ring* in Fig. 102*b* fits into precut grooves in the timber faces and is used in heavy construction. The *toothed-ring* in Fig. 102*c* is placed between the surfaces of two timbers, without previous preparation to receive it, and is forced into the timbers by pressure to produce joints in light construction. The *shear plates* in Fig. 102*d* are used in

pairs with each unit let into a prepared depression or dap in the timber face until its back is flush with the surface of the timber; or else one unit is inserted into a timber member so that a metal member can be

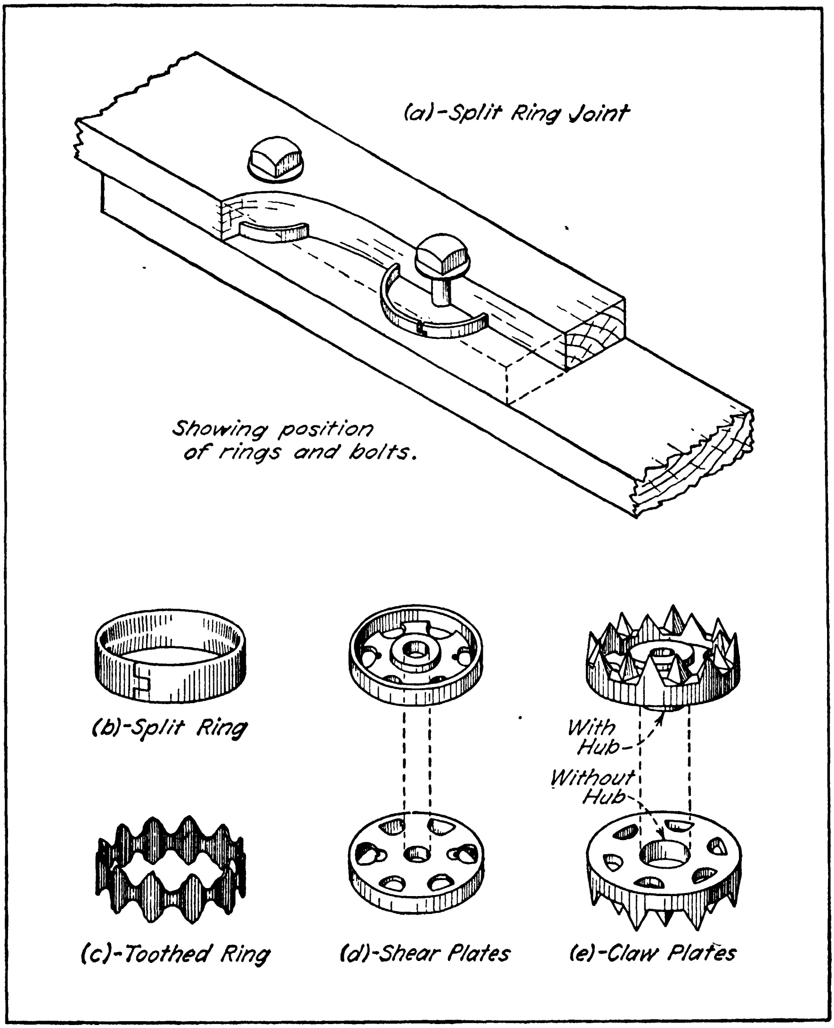


FIG. 102. Modern Connectors

bolted to it. In either case, the stress is transmitted between members by shear in the bolt. The *claw plates* shown in Fig. 102*e* are used in the same manner as shear plates, but the dap is not made deep enough to receive the teeth which are forced into wood below the depth of the

dap. These units are made for use singly or in pairs. One has a flush back, whereas the other has a projection which fits into the hole of the other so that stress can be transferred across the joint by the units themselves without producing shear in the bolt. Either one of the units can be used to connect a metal member to a timber member. If it is desirable to relieve the bolt from the shearing stress, the hole in the metal member is made large enough to receive the projection on the back of the claw.

Each type of connector is available in several sizes and capacities. The number of connectors required in any joint is determined by the stresses in the members.[3]

ARTICLE 37. FRAME WALLS AND PARTITIONS

Wood-Stud Construction. Walls and partitions whose structural elements are wood are classed as *frame construction.* These structural elements are usually closely spaced, slender vertical members called *studs,* arranged in a row, with their lower ends bearing on a long horizontal member called a *bottom plate* or *sole plate,* and with their tops capped with another plate called a *top plate.* Short members called *bridging* or *firestopping,* placed horizontally, or approximately so, are cut in between the studs at their midheight to give them lateral support and to restrict the spread of fire upward on the inside of the partition. The framing for walls and partitions of this type is shown in Fig. 103*a*.

The bearing strength of stud walls and partitions is determined by the strength of the studs acting as struts or columns. The spacing of studs is usually 12 in. or 16 in. so that they will support, without waste, wood lath with the standard length of 4 ft. A 24-in. spacing is too great for ordinary wood lath. Metal-lath lengths are made to conform to the 12- and 16-in. spacing of studs. Many accessories, such as heating ducts, batt insulation, etc., are designed for 16-in. spacing of studs and can not be readily adapted to 12-in. spacing.

The minimum size of stud permitted in walls and partitions is usually 2 by 4 in. for 1-story and 2-story buildings. The first-story studs for 3-story buildings should be 2 by 6 in. The loads to be carried may require the use of larger sizes. Studs should be firestopped, as shown in Fig. 103*b*, where they pass through a floor. The angles at the corners where stud walls or partitions meet should be so framed that lath can not extend from one room to another. Double studs should be provided at the sides of all openings, and double headers on edge should be provided across the tops and bottoms and should run between uncut studs, as shown in Fig. 103*d*. The ends of the bottom header should rest on short studs, as shown. All openings over 4 ft. should be trussed.

At points where stud partitions meet masonry walls, a sufficient number of bolts should be built into the masonry to tie the last stud adequately to the masonry.

A partition which is not supported by a wall or partition below should be supported by girders or double joists if it runs parallel to the joists,

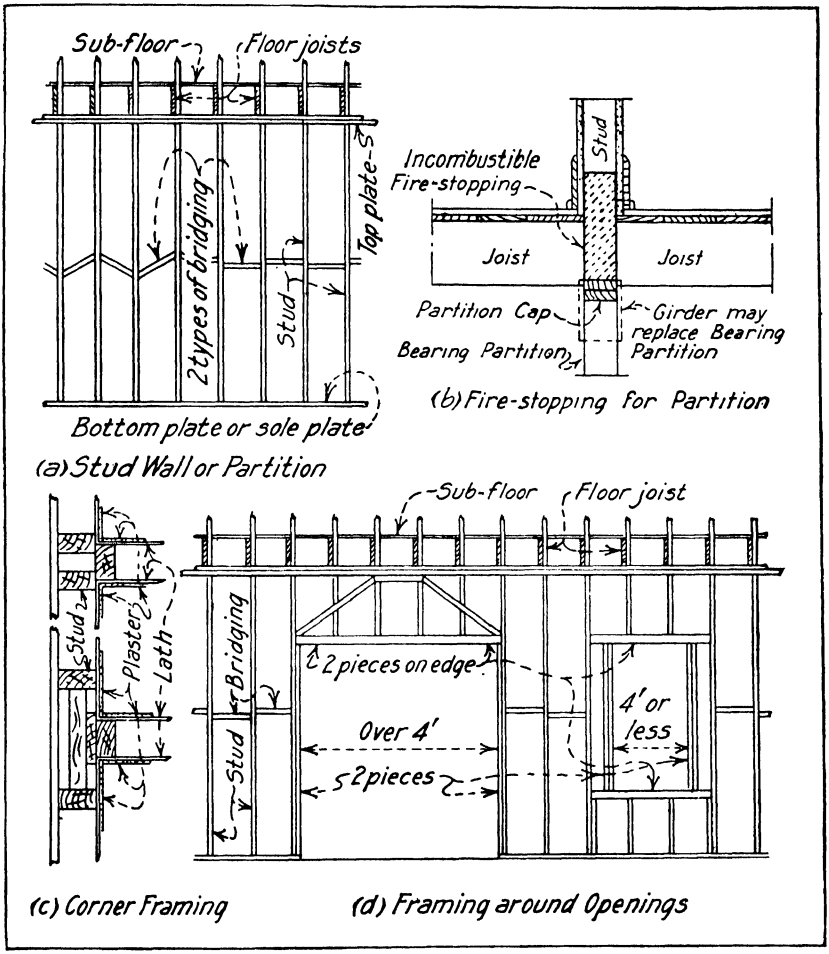


FIG. 103. Frame Walls and Partitions

or by a bottom or sole plate if it is placed at an angle to the joists of the floor below. All such partitions should be trussed by cutting in diagonal pieces of the same material as the studs and by running in a continuous line upward from each lower corner of the partition to a point at the

top as near the center of the partition as possible. Openings in such partitions will determine the arrangement of the diagonal members.

When the studs of bearing partitions are placed directly below each joist, it is desirable, but not essential, that a double top plate be used. Although non-bearing partitions do not require double plates, they are desirable here also.

It is common practice in framing partitions to place the lower ends of studs on a sole plate placed on top of the sub-floor instead of running the studs through the floor to the top plate of the studs for the story below. This practice is objectionable unless the outside wall is framed in the same way because the side shrinkage of the floor joists, the sub-floor, and the plates at each floor cause considerable settlement; and, if there is not a corresponding shrinkage in the outside walls, the unequal settlement will cause bad plaster cracks in the partitions which have one end at an outside wall. If the outside walls are of masonry, this shrinkage will, of course, not be present. In the *balloon frame*, Fig. 104*a*, the outside studs are continuous for two stories; so the only side shrinkage is in the sill which rests on the masonry wall. The same is true of the *braced frame*, Fig. 104*b*, except for the side shrinkage of the girt on which the joists rest. A type of construction known as the *platform frame* or *western frame* uses studs which extend through one story in the outside walls as well as in the partitions, as shown in Fig. 104*c*. In both cases the studs are placed on a plate resting on the sub-floor so that the shrinkage is equalized and the plaster cracks are avoided.

In Fig. 104*a* and *b* the first-floor joists are not placed on top of the girder in the basement but rest on strips nailed to the sides of the girder and along the bottom edge. This detail reduces the settlement due to side shrinkage. These strips are called *ledger strips*.

Side shrinkage may be ½ in. or more in 12 in. and may amount to as much as 2 in. in a poorly constructed two-story building. End shrinkage is much smaller than side shrinkage and is not a serious factor. Seasoned lumber shrinks much less than green lumber and quarter-sawed lumber much less than flat-sawed. Swelling due to the absorption of moisture has the opposite effect from that of shrinkage. As atmospheric conditions change, a timber frame is constantly moving owing to shrinkage and swelling. It is important to reduce these factors to a minimum.

A wood sill or plate not less than 2 in. thick and with a width at least equal to that of the wall framing supported by the sill should be provided under all stud walls and partitions which rest on masonry foundation walls. It is desirable to place a sheet of waterproof mate-

rial between the plate and the top of the masonry wall to insure against the transmission of dampness from the wall to the wood construction. Sheets of non-corrodible metal like copper are used under masonry walls, but strips of heavy bituminous roll roofing are probably adequate for frame construction. It is desirable to cement these to the foundation wall with bituminous cement. Because of the prevalence of sub-

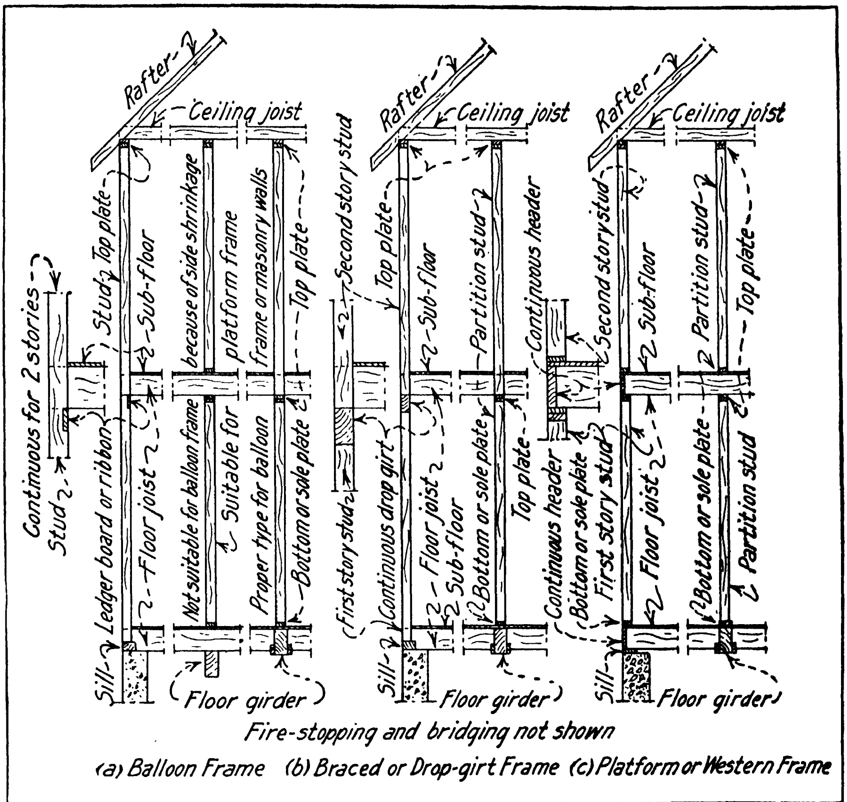


Fig. 104. Frame Construction

terranean termites in nearly all parts of this country, as mentioned in Art. 8, no wood frame should be constructed without termite protection. The simplest and most effective method of providing such protection is by means of *termite shields*, illustrated in Fig. 9.

Sheathing. For most forms of outside covering which are applied to the exterior of wood-stud walls, it is first necessary to cover the entire surface with sheathing to increase the rigidity and heat-insulating

properties of the wall. This sheathing may be wood boards with a nominal thickness of 1 in., fiber board at least $\frac{1}{2}$ in. thick, gypsum board at least $\frac{1}{2}$ in. thick, and plywood at least $\frac{5}{16}$ in. thick.

Wood sheathing boards may be plain, matched, or shiplapped. They should have a nominal width of at least 6 in. and should be nailed to each stud with not less than two 8d common nails, three nails being desirable in 8-in. boards. They may be placed horizontally or diagonally. Horizontal sheathing is somewhat cheaper than diagonal sheathing but is lacking in rigidity. To partially remedy this lack of rigidity, diagonal braces are provided at the corners. These are preferably continuous 1- by 6-in. boards let into the studs but they may be 2- by 4-in. pieces cut in between the studs in a continuous line. Either type of bracing may interfere with the return ducts of forced hot-air heating systems. If a stucco facing is used, some architects would not use diagonal sheathing because of its supposed tendency to cause stucco cracks.

Fiber board is made of cane fiber, straw, or similar fibrous materials pressed into sheets 4 ft. wide and up to 12 ft. long, as described in Art. 62. They should be placed with the length parallel to the studs and should be nailed with galvanized large-head roofing nails $1\frac{1}{2}$ or 2 in. long, spaced 6 in. apart at intermediate studs and 3 in. apart at the edges. A special board with an asphalt coating is available if desired.

Gypsum board, as described in Art. 62, is made up of a gypsum core encased in a heavy waterproof building paper. The width used for sheathing is 2 ft., and the length up to 8 ft. The length is placed at right angles to the studs. Sheets are nailed in the same manner as described for fiber board.

Plywood is factory-made of three or more layers of wood joined with glue and laid with the grain of adjoining plies at right angles, as described in Art. 62. There is always an odd number of plies. The sheets are 4 ft. wide and up to 10 ft. long. They are nailed to the studs with 6d common nails spaced 6 in. at edge bearings and 12 in. at intermediate bearings.

Tests conducted by the United States Forest Products Laboratory indicated that the relative rigidities of stud walls of various types are about as follows:

1-in. horizontal sheathing without braces	1.0
1-in. horizontal sheathing with cut-in braces	1.6
1-in. horizontal sheathing with let-in braces	4.2
1-in. diagonal sheathing with no braces	4.3
$\frac{1}{4}$-in. plywood sheathing	5.9

Exterior Surfaces. The exterior face of wood-stud walls may be covered with boards of special design called *siding,* placed horizontally and nailed to the studs with or without an intervening layer of wood sheathing or fiber board. A heavy specially treated paper such as rosin-sized building paper, tar paper, or sheathing paper may be placed under the siding to make the surface more weather-tight. There are two general types of siding, i.e., *bevel siding* which is tapered or beveled so that it is thinner on the upper edge than on the lower edge, as shown in Fig. 105*a,* and which is lapped in laying; and *drop* or *novelty siding* which

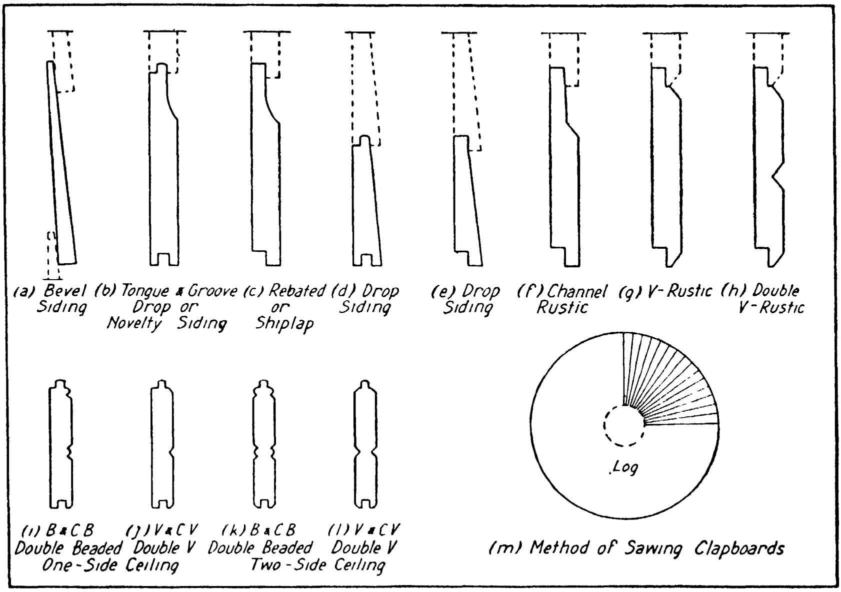


FIG. 105. Types of Wood Siding and Ceiling

has a tongue-and-groove joint or a *rebated* or *shiplap joint,* as shown in the various designs of Fig. 105*b* to *h,* some forms of which will give the same effect as bevel siding. Many other designs are manufactured. The common widths are 6 in. and 8 in. (nominal), and the thicknesses $\frac{9}{16}$ in. and $\frac{3}{4}$ in. (actual); but other widths and thicknesses are available.

Rustic sidings and *colonial sidings* are special forms of drop siding. Bevel siding is sometimes called *weatherboarding.*

Siding is made of Douglas fir, white and yellow pine, spruce, hemlock, redwood, cedar, and cypress.

Clapboards were used to a limited extent in the same manner as siding. They have about the same cross-section as bevel siding but taper

almost to a feather edge. As formerly made, all boards were quarter-sawed, for they were made by sawing a log radially into wedge-shaped boards, as shown in Fig. 105*m*. Due to the taper of logs, boards of uniform width could not be made very long without considerable waste. The usual length was 4 ft., and the width 6 in. or 8 in. They were lapped in laying, with 4 or 5 in. exposed or "to the weather." Clapboards are not now a commercial product.

The use of siding without sheathing is illustrated in Fig. 106*a*, and with sheathing in Fig. 106*b*.

Wood shingles may be applied to wood-board or plywood sheathing, as shown in Fig. 106*c*. They may be placed with more of the shingle exposed or *to the weather* than when used on roofs. Split shingles called *shakes* are used in the same manner as ordinary shingles, but since their length may be as great as 3 ft. they are laid with a considerable length to the weather. For a more detailed discussion of shingles see Art. 66.

Stucco surfaces are sometimes used on the exterior of wood-stud walls. Exterior surfaces should probably be portland-cement stucco, although lime stucco is also used. Stucco should not be used on wood lath. The various kinds of plaster and stucco and the methods of applying them are described in Art. 75. If wood lath are used, sheathing should be nailed to the outside of the studs. The wood lath are held away from the sheathing by wood *furring strips* placed vertically and 16 in. apart, as shown in Fig. 106*e* to enable the stucco to get a grip on the lath. The wall may be made tighter by using an asphalt-saturated felt paper between the sheathing and the furring strips. Unless the coating of stucco is water-tight, rain water will swell the lath, causing the stucco to crack.

If metal lath is used, crimped-metal furring strips are placed over the sheathing paper directly along the line of the studs and galvanized or painted metal lath with its long dimension horizontal is placed over the furring strips and fastened by nails or staples, passing into the studs as shown in Fig. 106*g*. Some forms of metal lath are ribbed and so do not require furring strips. Metal furring strips may be replaced by special furring nails.

In another form of exterior wall construction, using metal lath, the sheathing and waterproof paper are omitted and the furring strips, if used, are applied directly to the wood studs. The scratch coat and brown coat are applied to the exterior and then a backing coat $\frac{5}{8}$ in. to $\frac{3}{4}$ in. thick is applied to the interior surface of the exterior lath bonding to the scratch coat which was placed from the outside. The face of this backing coat should be about $\frac{1}{4}$ in. back of the face of the studs or, in

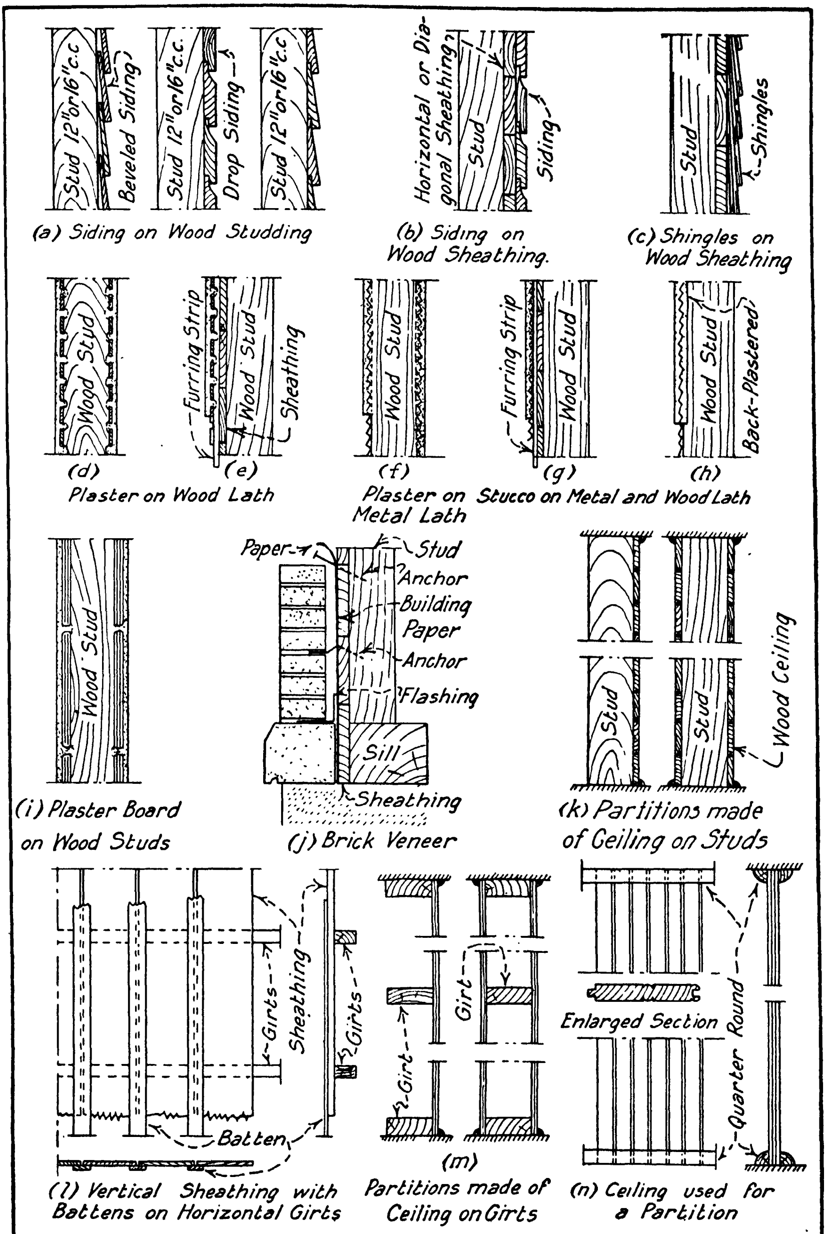


FIG. 106. Types of Frame Walls

other words, the studs should be embedded in the plaster about ¼ in. It may be desirable to paint the face of the studs to retard decay. This is known as *back-plastered construction* and is shown in Fig. 106*h*. This type of construction, using metal lath, will be sufficiently rigid if the corners of each wall are braced diagonally by 1- by 6-in. boards let into the studs on the inner side and securely nailed to them. The studs should be braced horizontally midway in each story height with 2-in. solid bridging cut in between the studs and kept 1 in. back from the face of the studs to clear the plaster keys.

Frame Walls Veneered with Brick or Other Masonry. Exterior walls with wood studs and some form of sheathing may be veneered

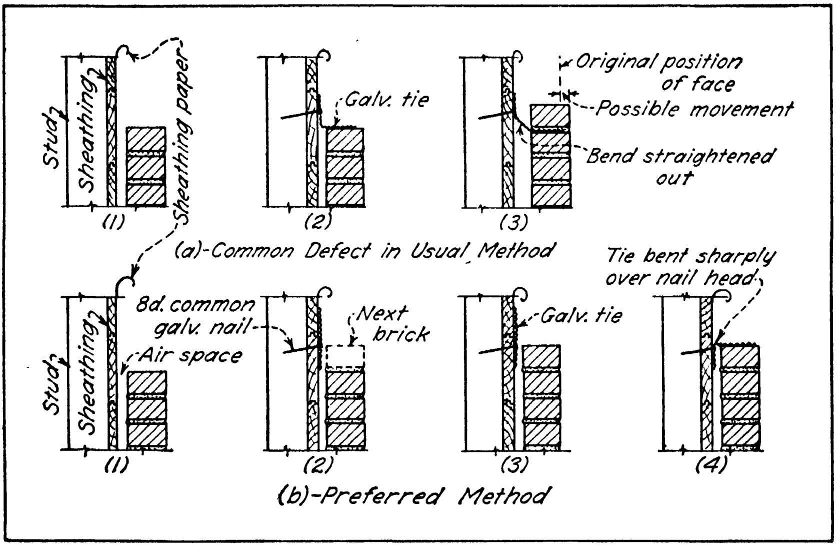


FIG. 107. Tying Face Brick to Wood Frame

with brick, as shown in Fig. 106*j*, or with other masonry. The veneer should rest directly on the masonry foundation of the structure and should be tied to the frame structure at intervals not more than 16 in. vertically and horizontally.

The weakest point in this type of construction is the tie between the face brick and the backing. A method which has been used to a considerable extent in the past is shown in Fig. 106*j*. It consists of a nail driven through the sheathing and into a stud. This should be a 40d common galvanized nail which will extend at least 1½ in. into the stud. The usual method of tying is illustrated in Fig. 107*a*. The masonry is brought up to the elevation at which the anchor is to be placed, as

shown in *1*. A corrugated brick tie, bent into the form of an L, is placed in the position shown in *2* and driven into a stud. If this method is used, the bend should be sharp; it should be placed at the height of the joint; and the nail should be driven into the bend. This practice is not usually followed, and an opportunity is given for the veneer to pull away from the frame, as shown in *3*. This can be avoided by the procedure illustrated in Fig. 107*b*. The masonry is stopped one course below the elevation of the tie, as in *1*; the tie is placed flat along the stud; and the nail is driven into the stud, as shown in *2*; another course of brick is laid, as shown in *3*; and the tie is bent sharply over the head of the nail and into the joint, as shown in *4*. If this procedure is followed the tie can not yield as it can in Fig. 107*a*. The nail in either method shown in Fig. 107 should be not smaller than an 8d common galvanized nail and should always be driven slightly inclined and into a stud.

An air space of about 1 in. should be left between the back of the brick and the sheathing, and a layer of building paper should be placed over the sheathing to increase the tightness of the wall. Openings should be carefully flashed, as shown in Fig. 64, to prevent the entrance of moisture behind the facing. Adequate fire stops should be installed at the intersection of the partitions with the walls. The frame construction should not extend below the first-floor joists. Provision must be made for any shrinkage in the timber frame, or else difficulties will be encountered where the window and door frames penetrate the masonry veneer.

Veneered construction resists exposure to exterior fires far better than frame construction. Its resistance to interior fires is about the same as that of frame construction, but if not properly firestopped difficulty may be experienced in extinguishing fires behind the brick facing. Veneered structures are dry and easy to heat.

Exteriors of Plywood. A plywood $\frac{3}{8}$ in. thick factory-made by hot pressing and by using a waterproof synthetic resin glue is sometimes used for exterior paneling and siding. The edge joints are sealed with a heavy white lead paste and covered with moldings.

Interior Surfaces. The interior surfaces of exterior wood-stud walls and both surfaces of wood-stud partitions are usually constructed of wood or metal lath or of gypsum or fiber lath, to form the base for plaster, as shown in Fig. 106*d*, *f*, and *i*; or of $\frac{1}{2}$-in. or $\frac{3}{8}$-in. plywood. Plaster is applied as described in Art. 76. Partitions may also be constructed of matched ceiling placed on one or both sides of wood studs, as shown in Fig. 106*k*.

Post and Girt Construction. In cheap and temporary buildings, the structural elements in frame walls and partitions may consist of widely spaced horizontal members called *girts,* running between wood posts which are the load-carrying elements. Girts are usually 2- by 4-in. members spaced 3 or 4 ft. apart.

For exterior walls, the exterior surface may consist of vertical sheathing nailed to the girts, the cracks in the sheathing being covered with wood strips called *battens,* placed on the outside, as shown in Fig. 106*l*. Corrugated steel, as described more fully in Art. 70, is also used for such surfaces.

Exterior walls of this type are not usually provided with a finished interior surface. Temporary partitions are quite commonly made of plywood, ceiling, plaster board, or fiber board that is placed on one or both sides of wood girts with no other finish, except possibly paint on ceiling and calcimine on plaster board. See Fig. 106*m*.

Ceiling is usually tongued-and-grooved, but may be shiplapped, and is finished with a bead or a V at the joint and in the center of the face, as shown in Fig. 105*i* and *j*. Since there is always a bead or V in the center of the face, ceiling is called *double-beaded* or *double-V;* or *bead and center bead* (*B,* and *C, B*) or *V and center V* (*V* and *C, V*). If the beads or V's are on both sides, as shown in Fig. 105*k* and *l*, it is called *two-side ceiling.* Ceiling is 4 in. and 6 in. (nominal) wide, and from $\frac{5}{16}$ to $\frac{11}{16}$ in. (actual) thick; the most common width is probably 4 in. and thickness $\frac{9}{16}$ in. The two-side ceiling would ordinarily not be used with girts but is particularly useful for the type of non-bearing partition, shown in Fig. 106*n*, where the ceiling is supported only at the top and bottom.

Fire Resistance. Frame partitions with 2-in. by 4-in. wood studs and metal or wire lath with $\frac{3}{4}$ in. of gypsum plaster on each side are given a 1-hour fire-resistance rating. If neat wood-fiber plaster is used, the rating is increased to 2 hours.

ARTICLE 38. WOOD COLUMNS

Wood columns are usually composed of a single piece varying in size from 4 in. by 4 in. upwards. Large timbers may have a hole bored along the axis, as shown in Fig. 108*a*, to enable the piece to season more uniformly throughout the entire section and thus to avoid radial cracks to a certain extent. The corners may also be *chamfered,* as shown in this figure, to make the columns more resistant to fire and to improve their appearance.

If a single piece of sufficient size is not available, several pieces may be securely fastened together. A column built up in this way is not as

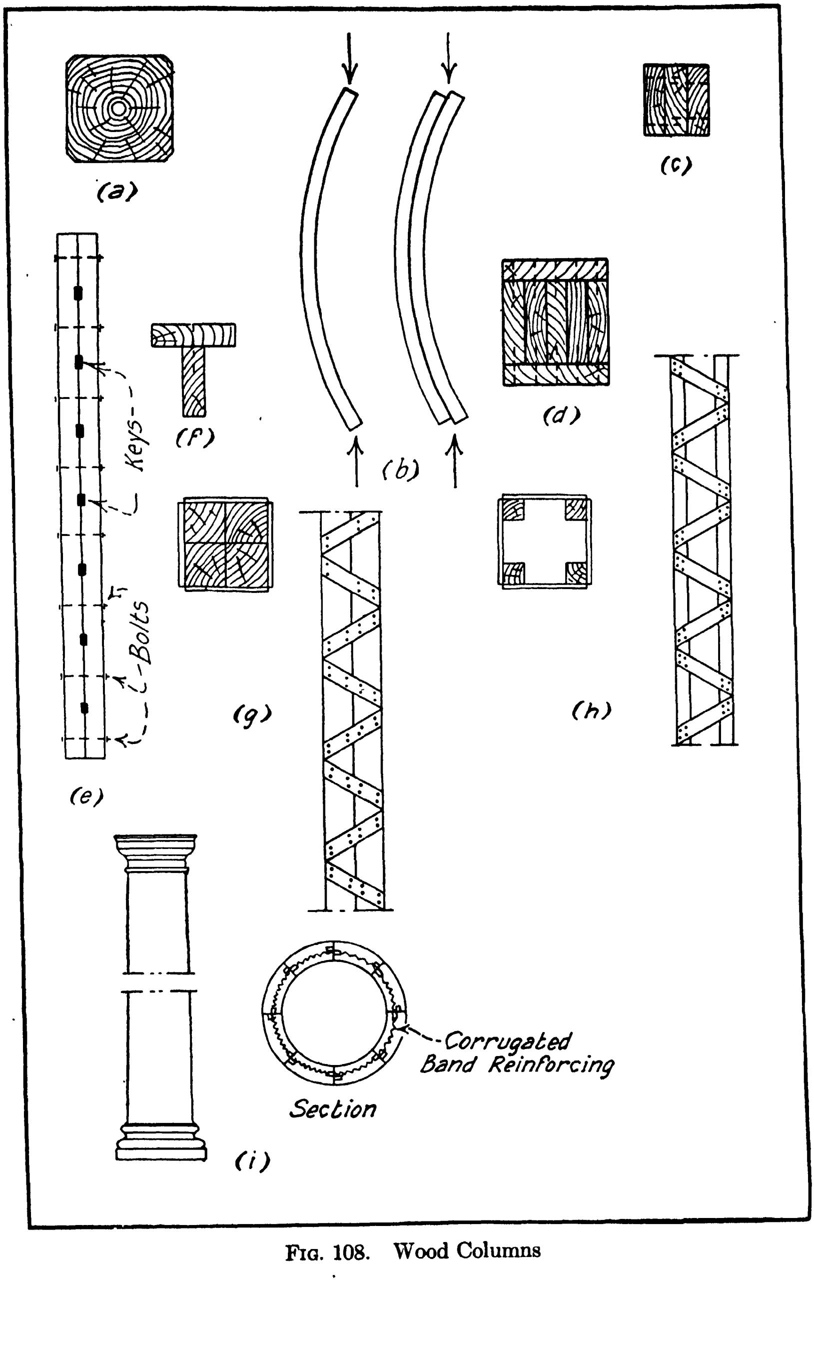


FIG. 108. Wood Columns

strong as a column of the same size composed of a single stick because the various pieces tend to act separately and not together as a unit. The action of a column consisting of one piece and of a column consisting of two pieces is illustrated in Fig. 108*b*. It will be noted that in the column consisting of two pieces those pieces tend to slide on each other and to act as separate pieces. Pieces fastened together, as shown in Fig. 108*c* do not act as a unit. The arrangement shown in Fig. 108*d* is better. The use of metal keys or connectors, as shown in Fig. 108*e*, is quite effective in keeping the members from sliding on each other. In this type of column, the members must be held in contact by bolts as shown in the figure. If connectors are used, the bolts pass through the connectors.

In the construction of forms and scaffolding the T section built up of two pieces, as shown in Fig. 108*f*, is more effective than a section using the same two pieces placed flat against each other.

Four pieces may be fastened together by wood lacing strips, as shown in Fig. 108*g*, or they may be spaced some distance apart and fastened by lacing strips, as shown in Fig. 108*h*, in long columns where rigidity is an important factor.

In slow-burning or mill construction the columns are of a single piece which must be at least 8 in. by 8 in. in section even though the load may not require a column that large.

Built-up wood columns, as shown in Fig. 108*i*, are extensively used to carry out architectural effects and not primarily to carry loads.

ARTICLE 39. WOOD BEAMS AND GIRDERS

The simplest and most common form of wood or timber beam or girder consists of a single piece, as shown in Fig. 109*a*. It may be as small as 2 in. by 4 in. for light ceiling joists or rafters in residences and as large as 12 in. by 24 in. where very heavy loads are to be carried over long spans. In slow-burning or mill construction, beams with a width less than 6 in. and a depth less than 10 in. are not permitted.

Very often a single piece of the required strength can not be obtained or it may be more convenient to fasten several pieces together, as shown in Fig. 109*b*, forming a *built-up beam*, the pieces being set on edge. If the pieces are only 2 in. thick they may be spiked together, but for larger pieces bolts are usually required. If such beams are to be exposed to the weather, water will soak in between the pieces and cause them to rot. For this reason *separators* may be used, as shown in Fig. 109*c*. Separators also permit heavy timbers to season more readily, and the danger of dry rot is avoided. The use of separators on the interior of buildings is objectionable, for fire in the small space

between pieces would be very difficult to put out. If heavy timbers are placed in contact with each other, the surfaces of contact should be given some preservative treatment to prevent dry rot. Beams built up in this way are very satisfactory and are often stronger than beams of the

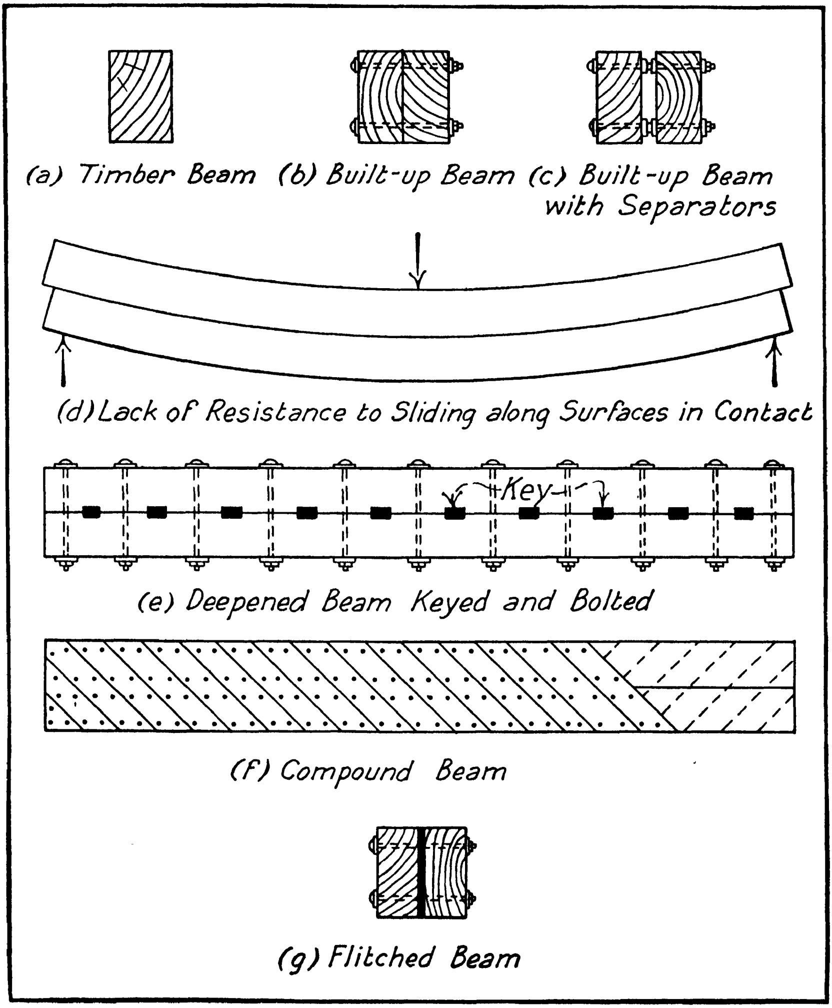


FIG. 109. Wood Beams

same size made of one piece, for defects which exist in one piece of a built-up beam are not likely to come directly opposite defects in other pieces; while, if a beam is composed of a single stick, a defect may exist throughout the entire width and seriously weaken the beam.

If one piece of timber is placed on top of another to act as a beam, these pieces will slide on each other along the surface of contact, as shown in Fig. 109*d*, when a load is applied. If this sliding is prevented so that the two pieces act as a unit, the beam thus formed will be equal in strength to a beam of equal size composed of a single piece. Bolts or spikes do not prevent this sliding but hardwood or metal keys and modern connectors, as shown in Fig. 109*e*, give satisfactory results

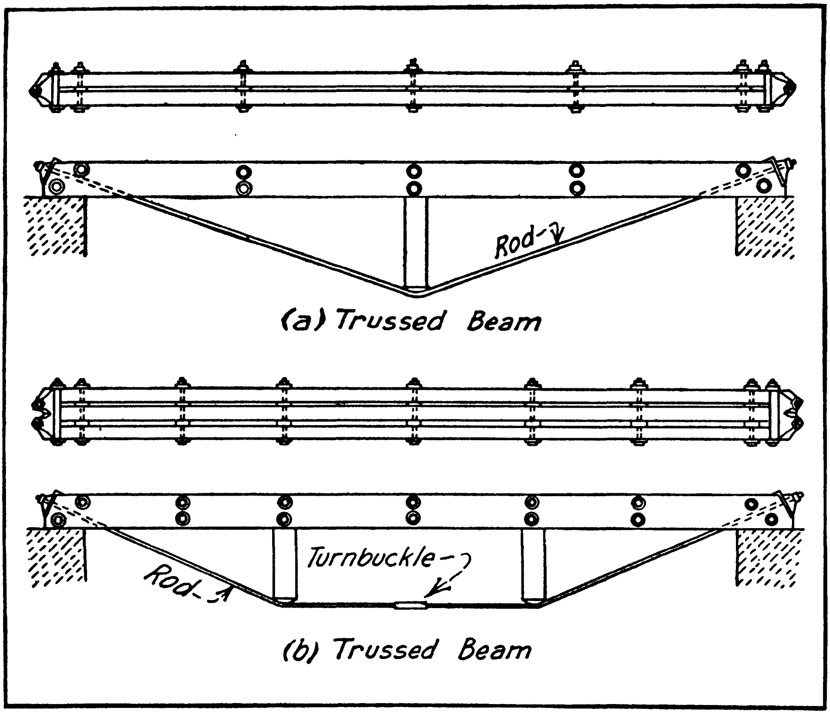


FIG. 110. Trussed Beams

if properly designed and constructed. It is also necessary to provide vertical bolts to hold the pieces in contact as shown in figure. This type of beam is called a *deepened beam*. Another method of accomplishing the same result is by the use of diagonal boards nailed to the sides of the pieces as shown in Fig. 109*f*. This method is not as effective as that making use of keys but may be more easily accomplished. Built-up beams of these types are rarely used.

Beams may be built up of timbers set on edge with steel plates between them, the several pieces being bolted together as shown in Fig.

109*g* to form *flitched beams*. Such beams are uneconomical but they are used to a limited extent to meet special conditions.

Trussed beams, as illustrated in Fig. 110*a* and *b*, are satisfactory types and are extensively used. The type shown in Fig. 110*a* is sometimes called an *inverted king-post truss*, and that shown in Fig. 110*b* an *inverted queen-post truss*. The end connections for the rod may be made of cast iron, as shown in the figure, or they may be built up of structural steel sections. Two rods may be used instead of one rod as shown. The top member may be built up of several thicknesses of 2-in. material spliced by staggering the joints.

ARTICLE 40. WOOD TRUSSES

Make-Up of Members. The various types of trusses are discussed in Art. 34. The upper chord is always made of wood and may be a single stick, several pieces placed side by side, or several pieces placed one on top of the other as in curved chord trusses. The lower chord may be a single stick, several pieces placed side by side, or steel rods. The other members which carry compressive stresses are made of one or more pieces of timber, and those which carry tensile stresses may be made of steel rods or wood.

Truss Joints. The joints in wood or timber trusses are made in many ways. They may be made by cutting the members so that they fit into each other in such a way as to provide for the stresses, bolts being used where necessary to hold the members together; by using steel *connection* or *gusset* plates and lag screws or bolts; by using

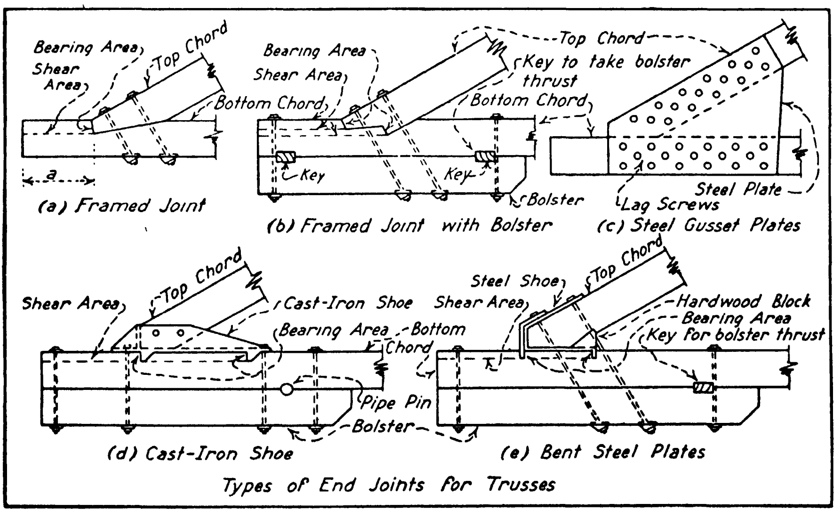


FIG. 111. End Joints for Wood Trusses

specially shaped cast-iron or timber blocks; and, more recently, by using metal *connectors*.

The end joints are usually the most difficult ones to design and construct. The simpler type shown in Fig. 111*a* is only suitable for use where the stresses are small. The joint tends to fail by bearing on the end of the inclined member and by shearing along the dotted plane. The length, *a*, must be made great enough to provide an area sufficient to resist the tendency to shear. This is not usually feasible if the stresses are large. The bolts must be large enough to hold the joint together yet they do not assist directly in transmitting stress.

The end joint shown in Fig. 111*b* is more elaborate but depends upon the same principles as that shown in Fig. 111*a*. The inclined member is more effective in bearing and the area resisting shear is larger than in the previous detail. A part of the shearing tendency is exerted on the upper dotted area, but the lower area must carry the full shearing stress. The short member on the lower side is called a *bolster*. It is provided to make the joint more substantial but does not carry any calculated stress. The diagonal bolts, provided to hold the joint together, pass through the bolster at an angle and tend to make it slide along the horizontal member. This tendency is resisted by hardwood keys, as shown in the figure.

An end joint that uses steel gusset plates is shown in Fig. 111*c*. One gusset plate is placed on each side of the joint. These plates are preferably fastened to the members by means of lag screws instead of bolts, for it is difficult to bore the holes into the timber so accurately that the bolts passing through the plate and the holes in the timber will fit the holes in the other plate without forcing the bolts in such a way as to impair the strength of the connection. The joint depends for its strength upon the lateral strength of the lag screws inserted in the timber.

The use of a cast-iron block in an end joint is illustrated in Fig. 111*d*. The projections or lugs on the lower side of this block must have sufficient bearing area so that the wood will not be overstressed, and there must be enough length between the lugs and the end of the member so that the joint will not fail by shear along the dotted plane. Since there are no inclined bolts used, the bolster does not tend to slide and no keys are required between the bolster and the horizontal member. A pipe key or pin is used, however. The bolster does not carry calculated stress but makes the joint more substantial.

An end joint that makes use of bent steel plates in place of the cast-iron joint described is shown in Fig. 111*e*.

The joint at the peak or apex of a truss is quite simple, for the horizontal thrusts or stress components of the chord members balance each other. The vertical thrusts or stress components of the chord members

are balanced by the stress in the vertical rod in the center of the truss. This stress is transmitted through a plate or bent washer at the apex, as shown in Fig. 112*a*. Steel or wood plates are bolted to each side of the truss at the joint to assist in holding the chords in position.

The center joint on the lower chord is also a simple joint, for the chord stresses on each side balance each other and are not transmitted

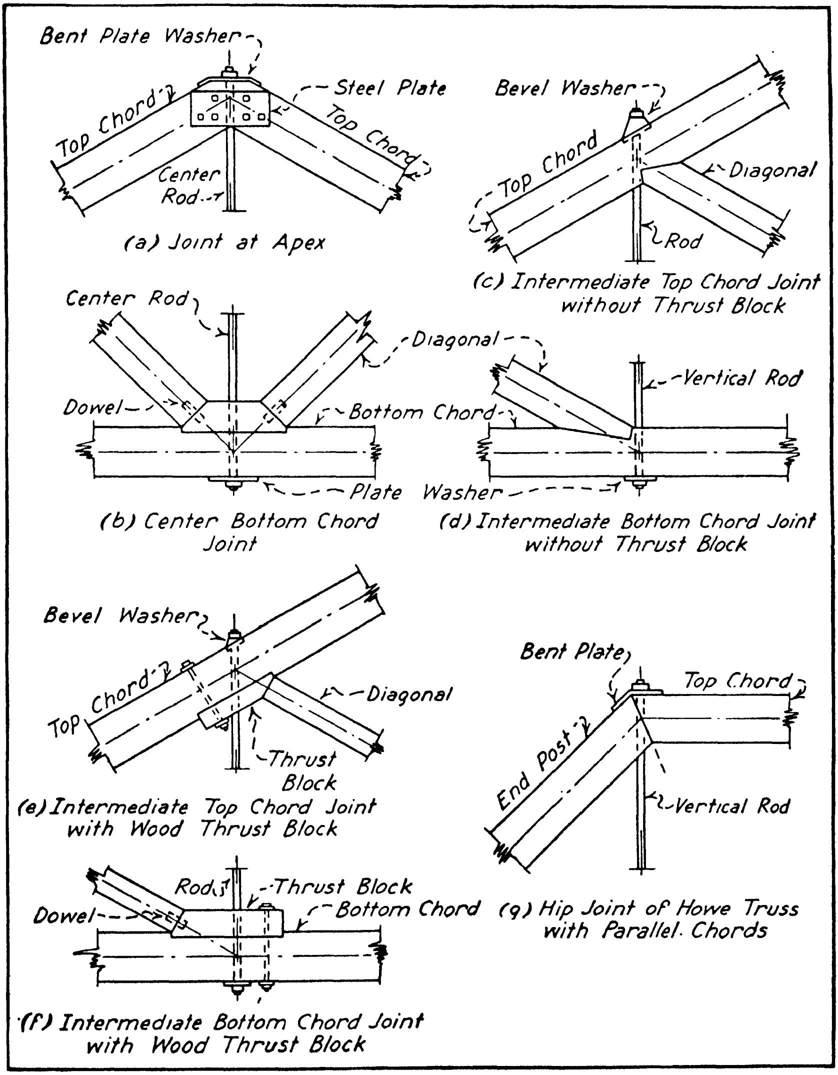


FIG. 112. Intermediate Joints for Wood Trusses

through the joint if the chord is not spliced at this joint. The horizontal thrusts or stress components of the diagonal members, meeting at this

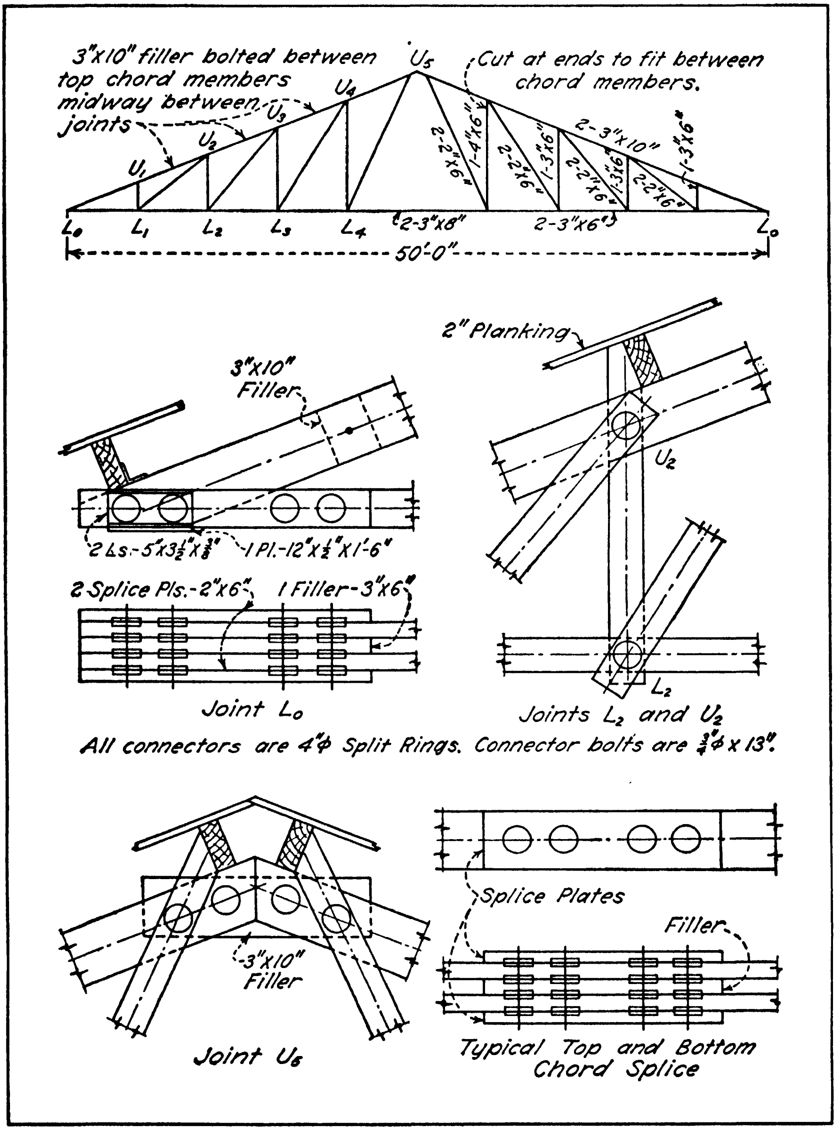


FIG. 113. Joint Details of Wood Pratt Truss Using Connectors

joint, balance each other for symmetrical loads and the vertical thrusts or stress components are equalized by the stress in the center vertical

rod. The ends of the diagonal members bear on a timber or cast-iron *thrust block* and are held in position by *dowels*, as shown in Fig. 112*b*. The thrust block is usually set a short distance into the chords. A washer or plate is placed on the end of the vertical rod.

Other diagonal members bearing on the top or bottom chord carry relatively small stresses and may be notched into the chord as shown in Fig. 112*c* and *d*.

Intermediate joints on the top and bottom chords may make use of wood thrust blocks, as shown in Fig. 112*e* and *f*, or cast-iron thrust blocks must be used. The thrust blocks must be set deep enough into the chords so that the bearing at the end of the block is sufficient to take the component of the stress in the diagonal member in the direction of the chord.

A detail for the hip joint of a Howe roof truss with parallel chords is shown in Fig. 112*g*.

Details of several joints of a Pratt roof truss using modern connectors are shown in Fig. 113. The locations of the connectors in the elevation are indicated by circles, and on top or bottom views and horizontal sections by small rectangles. It should be noted that trusses of this type can be built of 2-in. and 3-in. material. Joints using connectors are simpler, cheaper to construct, more positive in their action, and less affected by shrinkage of the wood than are framed joints.

The simplest form of timber roof truss is shown in Fig. 114*a*. It is suitable only for spans of 20 or 30 ft. Other simple forms of timber truss are the *king-post truss* shown in Fig. 114*b*, the *queen-post truss* shown in Fig. 114*c*, the *inverted king-post truss* shown in Fig. 110*a*, and the *inverted queen-post truss* shown in Fig. 110*b*. These inverted trusses are commonly called *trussed beams*.

A Howe roof truss with inclined top chords is shown in Fig. 115, and a Howe truss with parallel chords in Fig. 116*a*.

A bowstring roof truss is illustrated in Fig. 116*b*. The top chord consists of two sets of 2-in. timber bolted or glued together, forming a laminated member. The end joint makes use of a steel plate bent in the form of a U to receive the top chord and fasten to the lower chord. The web members in this form of truss carry very little stress; so it is not serious if the center lines of the members do not meet in a point at the joints.

The lattice truss shown in Fig. 116*c* makes use of 2-in. material bolted or tree-nailed together. The design of trusses of this type is largely empirical. A lattice truss with a curved chord is illustrated in Fig. 116*d*. The truss shown here is manufactured by the McKeown Brothers Company of Chicago, at the building site or at the factory.

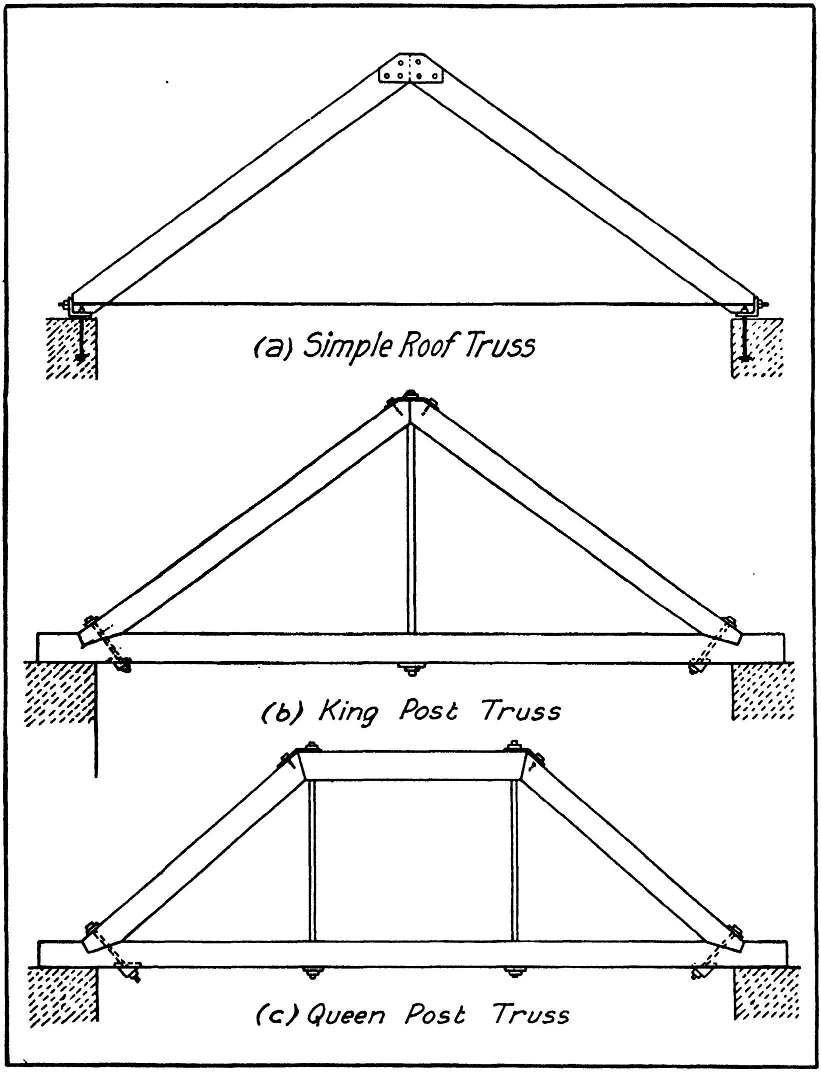


FIG. 114. Simple Roof Trusses

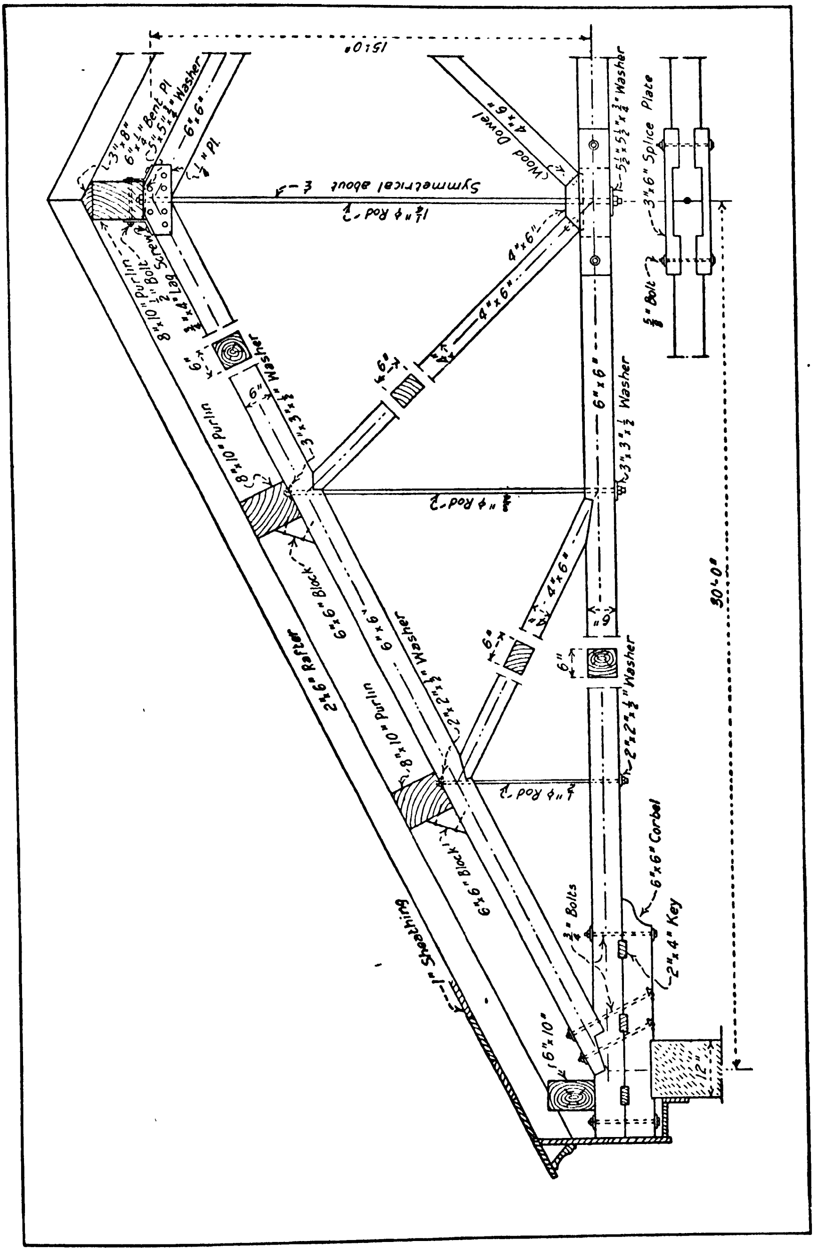


FIG. 115. Howe Roof Truss with Framed Joints

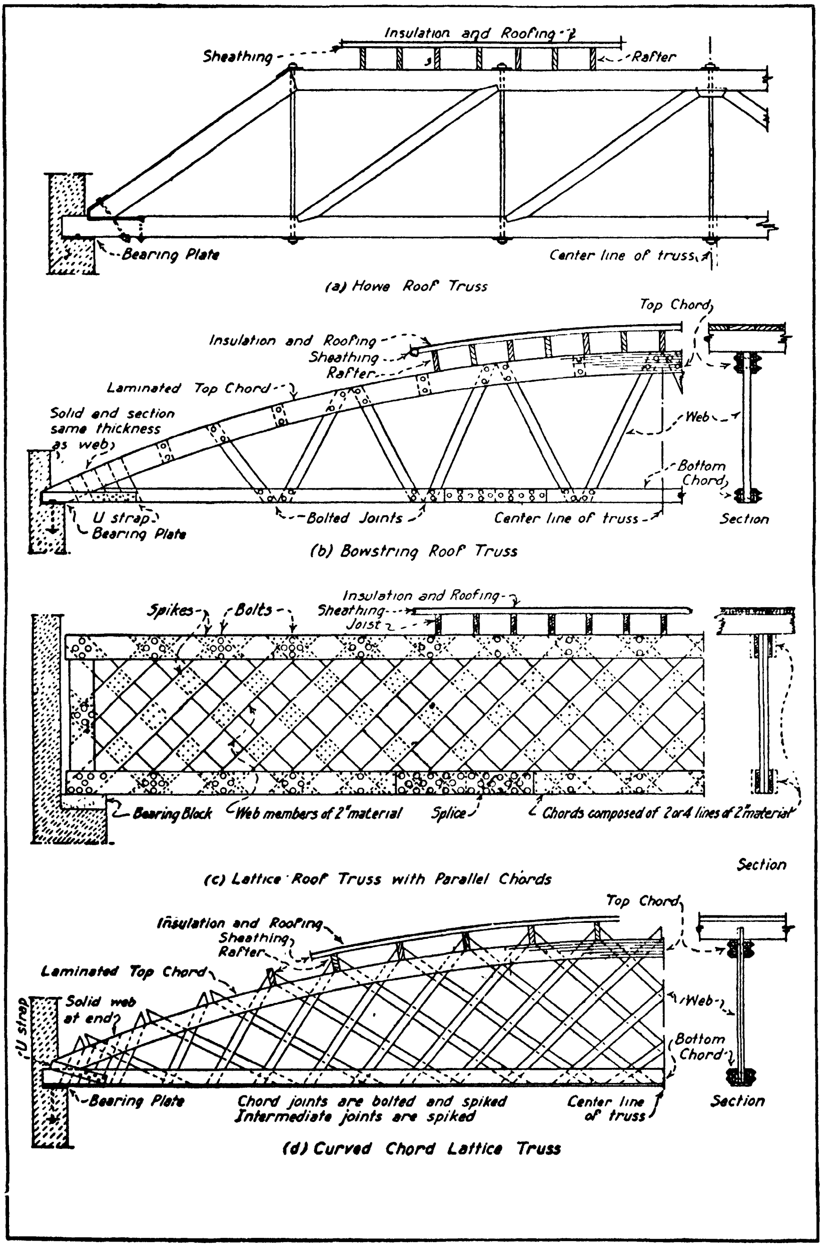


FIG. 116. Various Types of Wood Roof Trusses

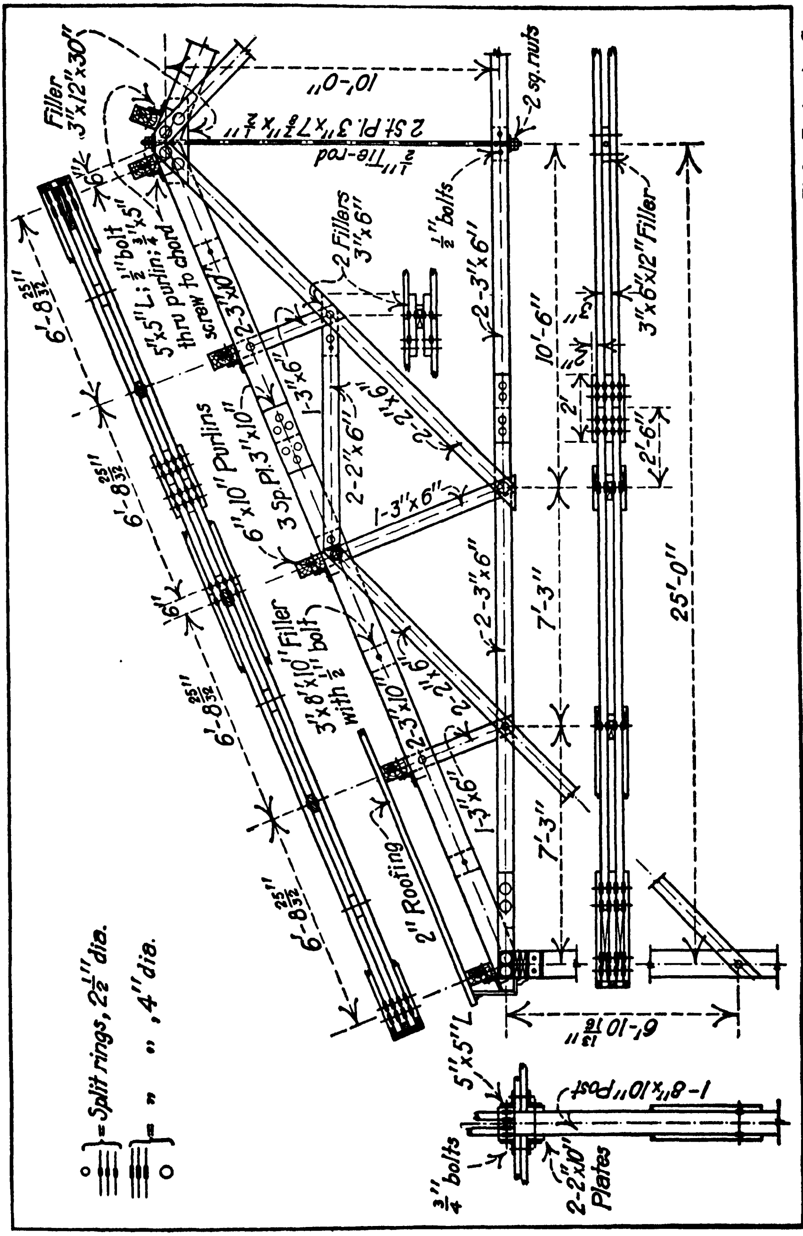


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FIG. 117. Wood Transverse Bent with Fink Truss Using Connectors

The trusses are shipped " knocked down." Trusses of similar design are made by other companies.

A wood transverse bent with a Fink truss, using the modern split-ring connectors illustrated in Fig. 102*c*, is shown in Fig. 117.[5] This type of construction is much simpler than the older forms that use framed and bolted joints.

A transverse bent with a span of 111 ft., using modern connectors in forming the joints, is shown in Fig. 118.[6] This was assembled on the ground and erected as a unit by means of a locomotive crane.

Lateral Bracing for Trusses. It is very essential that trusses be braced in a direction perpendicular to their length to keep them from failing by buckling and twisting. This is particularly true of the top chord which should be supported laterally at frequent intervals. Such support is usually provided by the roof deck. The bottom chords should be braced by lines of light trussed bracing in vertical planes perpendicular to the main trusses.

ARTICLE 41. WOOD ARCHES AND RIGID FRAMES

Arches. Wood or timber arches are used to support the roofs over large floor areas such as those required for drill halls, riding halls, gymnasiums, field houses, hangars, exhibition halls, and auditoriums.

The arches may be framed with all the members subjected primarily to direct stresses or else they may be ribbed. Two examples of three-hinged framed arches are given in Fig. 119. The chords of the arch in Fig. 119*a* consist of planks bolted together; the radial members are steel rods, and the diagonals single pieces of timber. The intermediate joints are formed of thrust blocks held in position by bolts. The chords of the arch in Fig. 119*b* are made of two pieces on edge, separated to simplify the joint details, and joined with a cover plank. Steel plates are utilized in forming the joints.

A simpler type of construction is illustrated in Fig. 120. It might be classed as a two-hinged framed arch or as a rigid frame. The joints are formed with modern connectors.

A wood arch may be constructed by bending boards to the required form and gluing them together to form a *laminated arch ring* of the desired dimensions. Arches of this type have been used in roof construction with spans of 125 ft. or more. They may be tied, as shown in Fig. 121*a*, or the thrusts of the arches may be taken by cantilevered buttressed walls, as shown in Fig. 121*b*. The rib itself may be so shaped that it can be carried down to the foundations; but, unless the rise of the arch is large in proportion to the span, such arches usually approach the rigid frame discussed in the next paragraph. The

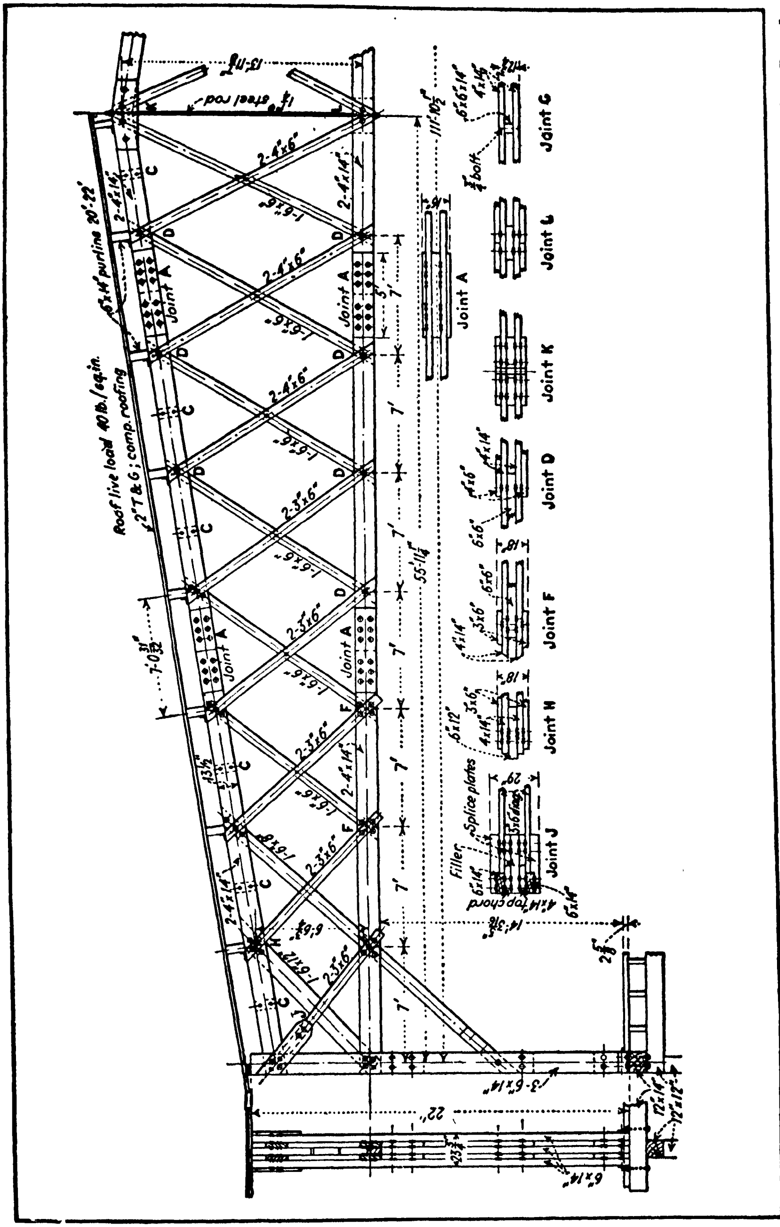

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FIG. 118. Wood Transverse Bent Using Connectors

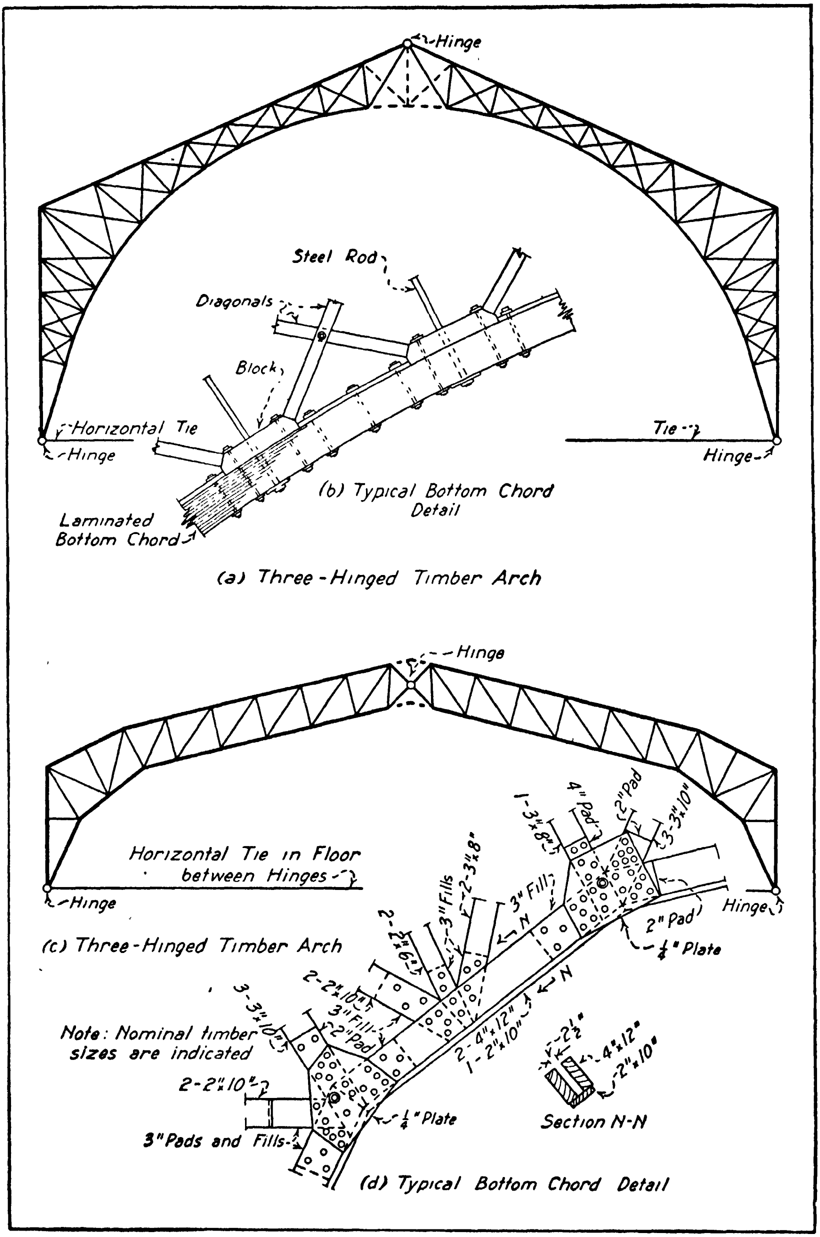

FIG. 119. Three-Hinged Wood Arches

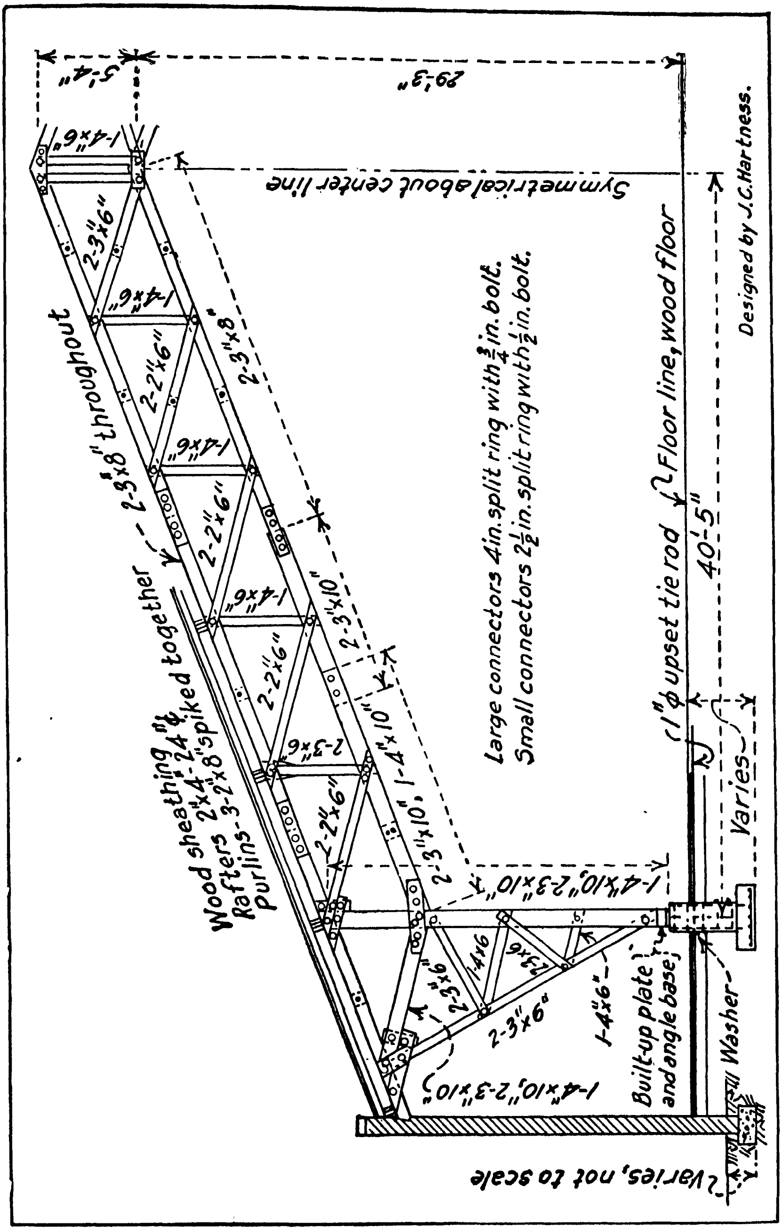

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FIG. 120. Two-Hinged Wood Arch or Rigid Frame with Connectors

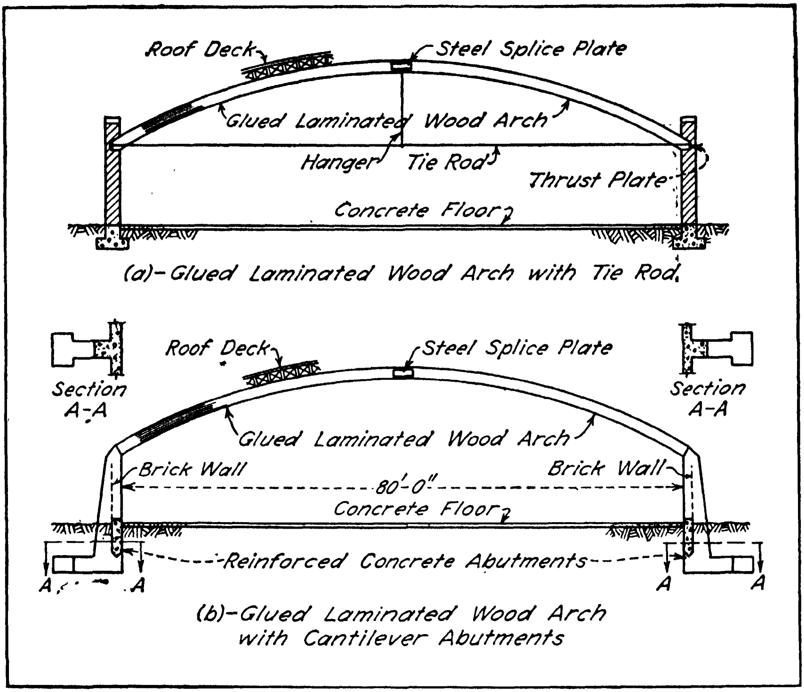

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FIG. 121. Glued-Laminated Wood Arches

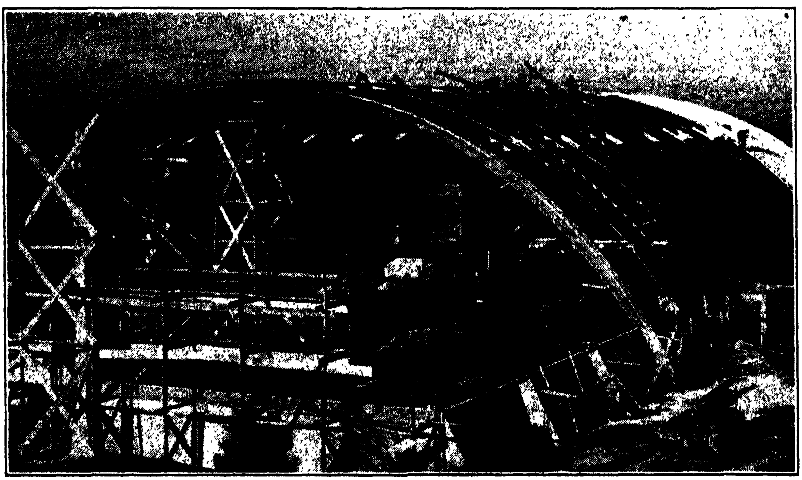

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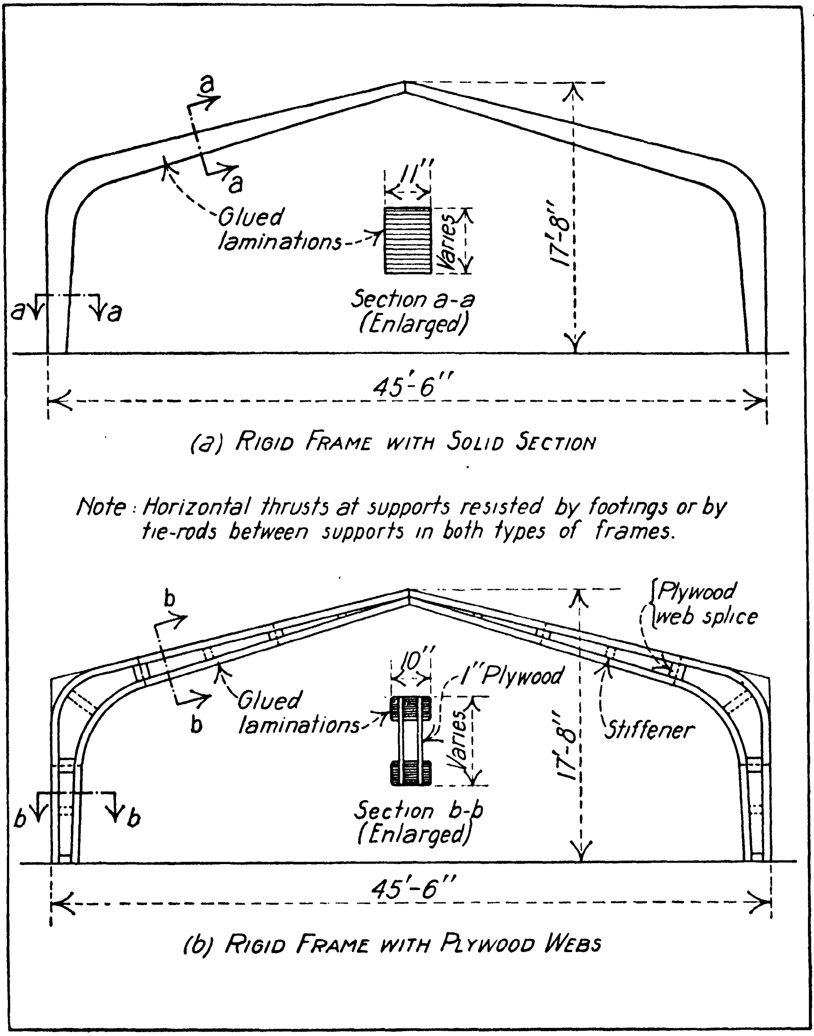
FIG. 122. Glued-Laminated Wood Arches with Buttressed Walls

laminations are made of boards of normal lengths with splices staggered so as to weaken the arch to a minimum extent. For a photograph of a laminated arch roof under construction see Fig. 122.

Rigid Frames. Rigid frames are built of boards bent to the right form and glued together, as illustrated in Fig. 123. In Fig. 123*a* the cross-section of the rib is solid, while in Fig. 123*b* plywood webs have



Forest Products Laboratory

FIG. 123. Glued-Laminated Wood Rigid Frames

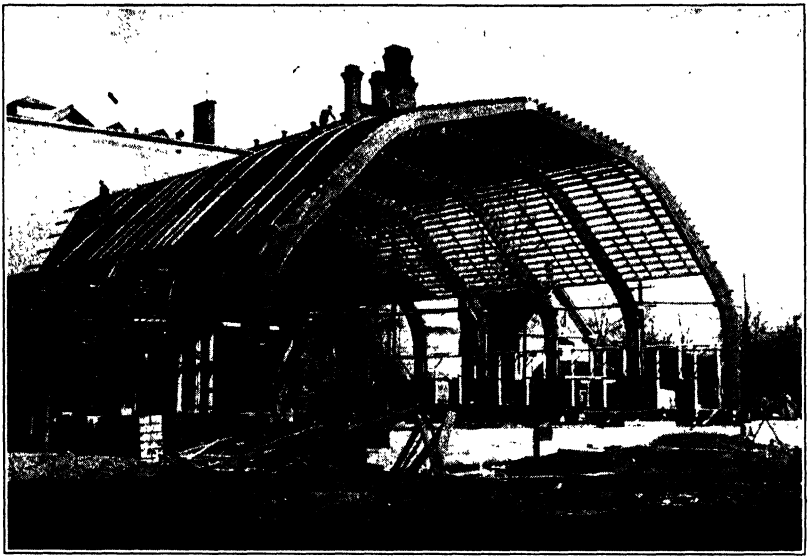


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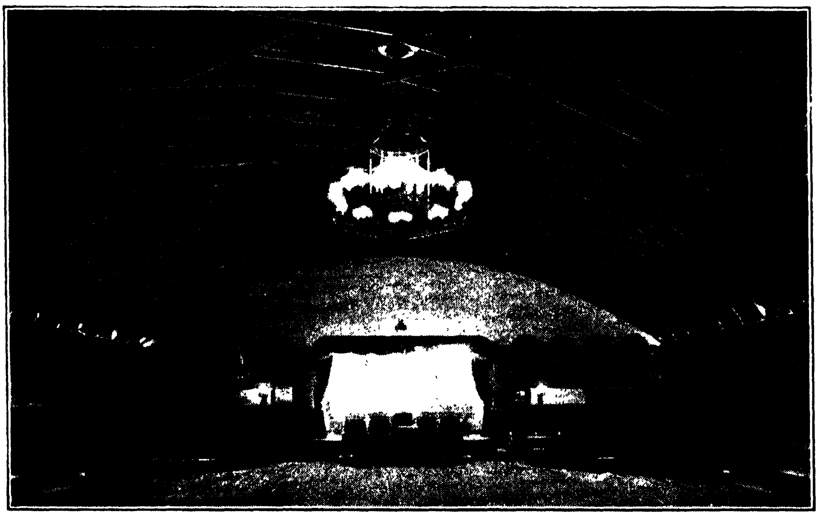
FIG. 124. Glued-Laminated Wood Rigid Frames or Arches



Lamella Roof Syndicate

FIG. 125. Interior of Wood Lamella Roof

been between laminated flanges. The frames may be spliced at the ridge, as would with the frames shown in the figure, or they may be designed as a single piece for the entire span. A building using glued-laminated rigid frames is shown in Fig. 124.

Lamella Roof. A special form of arched roof known as the *Lamella Roof* is constructed of short pieces of wood varying in size from 2 by 8 in. to 3 by 16 in., and in length from 8 to 14 ft. or of corresponding steel sections, as illustrated in Fig. 158. The short pieces called *lamellas* are bolted together in diamond-shaped patterns, as shown in Fig. 126*a*, to form a complete roof structure, as shown by the roof plan and longitudinal sections of a simple form in Fig. 126*b* and *c*. The interior view of a completed building is shown in Fig. 125. The diamond-shaped panels are all the sime size and shape. (The apparent curvature and distortion of the panels in Fig. 126*c* is due to the changing slope of the arched roof.) The thrust of Lamella Roofs may be taken by tie rods or by buttressed walls, as in the arches in Fig. 121. Roofs of this type have been used for spans from 25 ft. to 150 ft. on many types of buildings including gymnasiums, dance pavilions, exhibition buildings, auditoriums, churches, garages, warehouses, hangars, and sheds. Patents are held by the Lamella Roof Syndicate.

ARTICLE 42. WOOD FRAMING

Wood members may be fastened together by nails and spikes, screws, bolts, or modern connectors; by cutting the members to form joints, which may be fitted together, and by making use of bolts or dowels to hold them in place; or by steel plates and straps, or iron castings specially shaped to suit each case and used in connection with bolts. The present tendency is to avoid the types of joints which require a large amount of labor and to use modern connectors, bolts, spikes, plates, and castings as much as possible. The joining of small pieces of lumber in placing the finish and in building bookcases, cupboards, panels, etc., is classed as finish carpentry and millwork, and not as framing; but the joints used in this work will be included in this article.

Side Joints. The joints between two members placed side by side are called *side joints*. Such joints may be used in flooring, siding, panels, and millwork of various kinds. The common types are the *tongue-and-groove* or *matched joint*, the *rebated*, *rabbeted*, or *shiplap joint*, the *loose-tongue* or *spline joint*, and the *doweled joint*, as shown in Fig. 127*a* to *d*.

Angle Joints. In millwork and cabinet work two pieces which meet at right angles, as shown in Fig. 127*e*, may be joined by means of the *miter joint*, the *butt joint*, the *tongue-and-groove* or *matched joint*, the

shoulder joint, or the *dovetail joint*, or by various modifications of these joints, as shown in Fig. 127*f* to *o*. The *bead* shown on the shoulder joint and the tongue-and-groove joint casts a shadow which hides the crack where the two members join. These joints are glued where

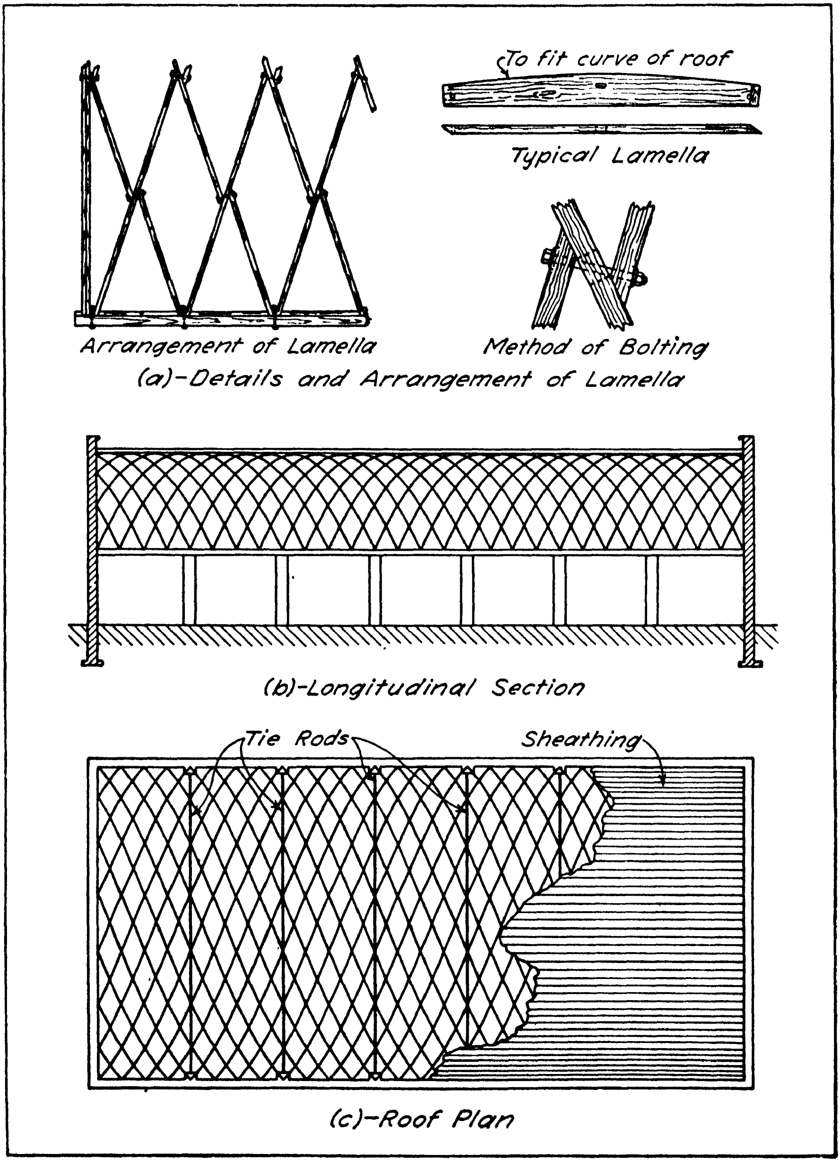


FIG. 126. Wood Lamella Roof

possible, but, if nails are necessary, finish nails with small heads are used. The nail heads are driven a short distance below the surface by using a nail set, and the hole thus formed is filled with putty after the priming coat of paint or varnish is on.

Framed Joints. The following types of joints are designed for members which frame into each other at an angle but are rarely used in building construction on account of the amount of labor involved in their construction.

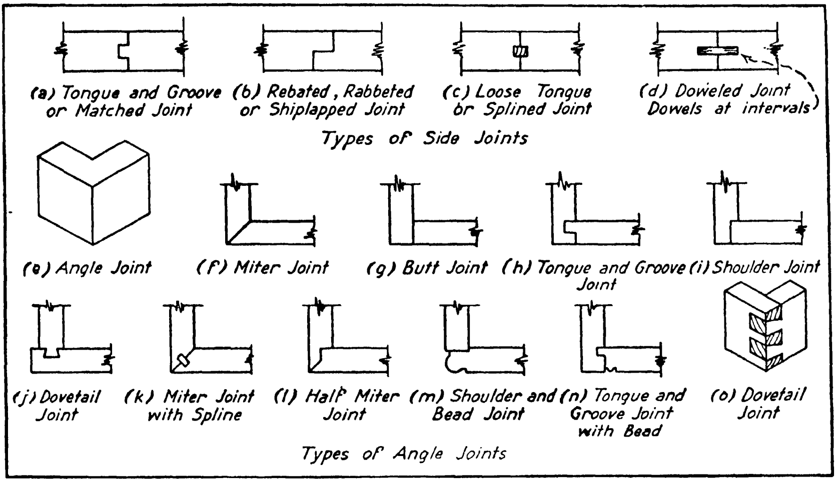


FIG. 127. Side and Angle Joints for Wood

A *mortise-and-tenon joint*, as shown in Fig. 128*a*, consists of an opening called a *mortise* in the side of one piece, into which fits the specially shaped end or *tenon* of the other piece. The tenon may be fastened into the mortise by means of a wood or steel pin.

Halving consists of joining two members, which meet or cross each other at an angle, by cutting a similar notch in each so that they will be flush on one face if they are not of the same thickness and on both faces if the pieces are of the same thickness. See Fig. 128*b*. If the members are beveled, as shown in Fig. 128*c*, to assist in holding them together, the operation is called *beveled halving*.

Housing consists of letting the entire end or thickness of one member into the side of another, as shown in Fig. 128*d*.

Notching consists of cutting a depression the full width of one member to receive another member, as shown in Fig. 128*e*. If both members are cut away, as shown in Fig. 128*f*, the process is called *double notching*.

The terms *gaining* and *dapping* have the same meaning as notching.

Cogging, as shown in Fig. 128*g*, is similar to double notching, but the depression on the face of one member does not go all of the way across. The uncut side of the face forms a ridge across the depression. This ridge is called a *cog*. The cog may be in the middle or on either side.

Splices or Longitudinal Joints. Timbers may be *spliced* or joined together longitudinally by lapping, scarfing, or fishing. The most common method is fishing, but the more simple forms of scarfing are used occasionally.

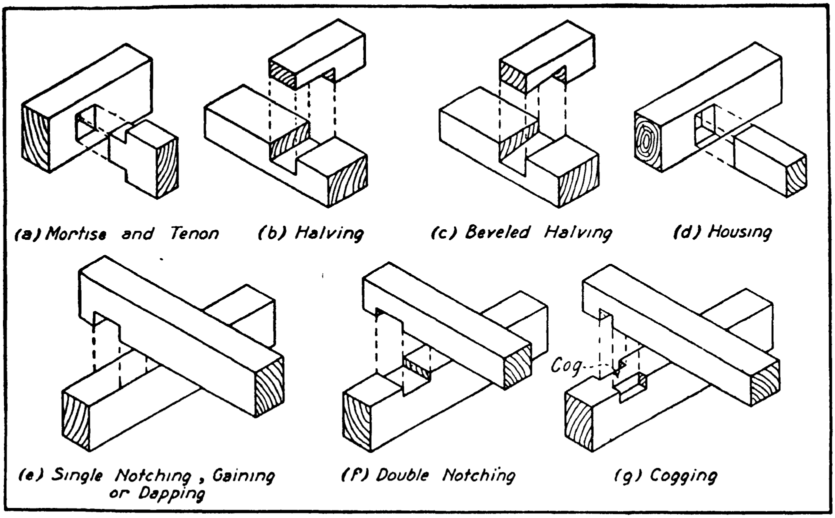


FIG. 128. Framed Joints for Wood

Lapping consists simply of lapping the end of one member over that of the other and fastening them together in some manner such as bolting or by using connectors. See Figs. 129*a* and 130*a*. This type of joint is not suitable for members carrying large stresses because of the eccentricity or distance between the axes of the members.

Scarfing consists of shaping the ends of the two members so that they may be fitted together and fastened without increasing the size at the joint. The simplest form of scarf joint is shown in Fig. 129*b*. It is called a *half-lap scarf joint* and is suitable for compression members.

The resistance of a scarf joint to tensile stresses can be increased in several ways which make it necessary to shear off one or more blocks of timber before the joint could fail. This is accomplished by inserting *keys* as in Fig. 129*c*, by *bevels*, or by *tables* as in Fig. 129*d* and *e*.

In all of these cases failure may occur in the joint or at the weakened sections at the ends of the joints.

Fishing consists of joining two pieces by means of wood or steel *fish plates,* as shown in Fig. 129*f*. The ends of the members butt together instead of lapping as in scarf and lap joints. The simple form of joint

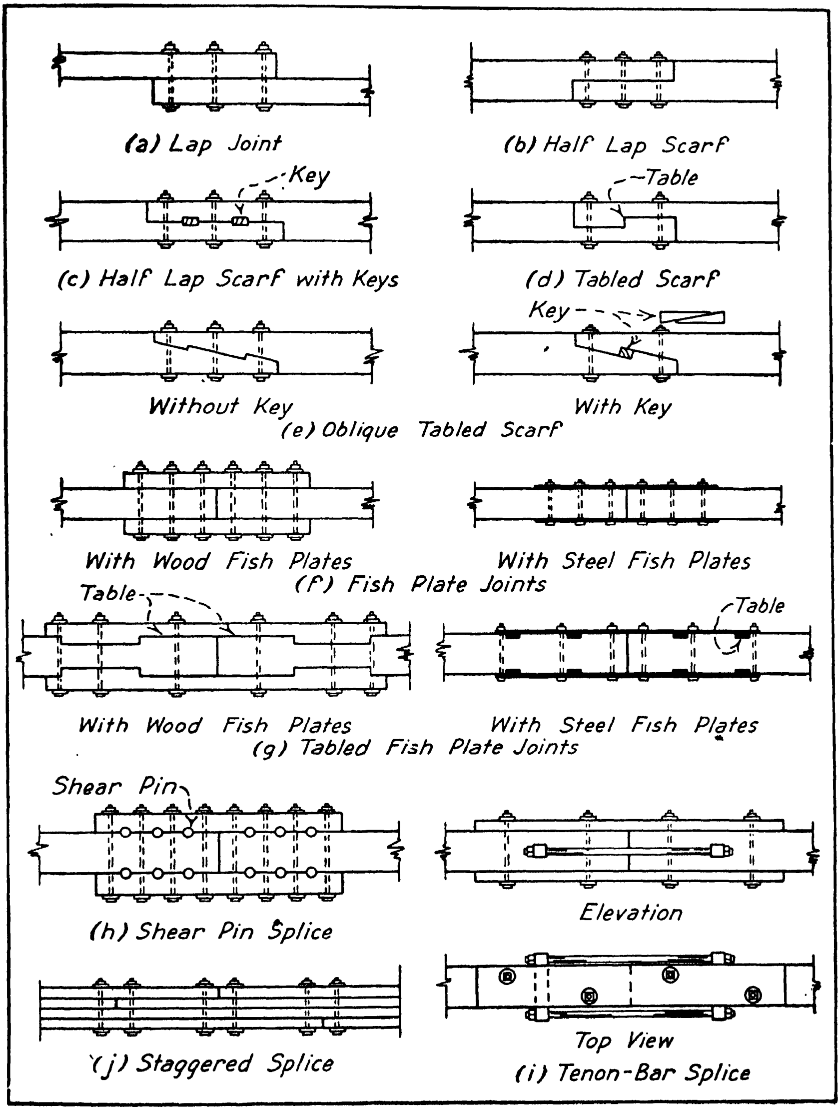


FIG. 129. Joints and Splices in Wood Members

is satisfactory for compression members where the function of the fish plates is to hold the members in line. Where tensile stresses are to be transmitted the *tabled fish-plate joints* shown in Fig. 129*g* may be used. Before these joints can fail, it is necessary to shear off the tables on one side of the joint. They can be so proportioned that they will develop a shearing strength equal to the strength of the reduced section of the member. A tabled fish-plate joint with wood fish plates and one with steel fish plates are illustrated in Fig. 129*g*. The steel fish plates consist of large plates with smaller plates, forming the tables, riveted to them. A fish-plate splice, with pins of steel pipe or hardwood taking the place of tables, is shown in Fig. 129*h*. The holes for the pins are bored after the joint is assembled.

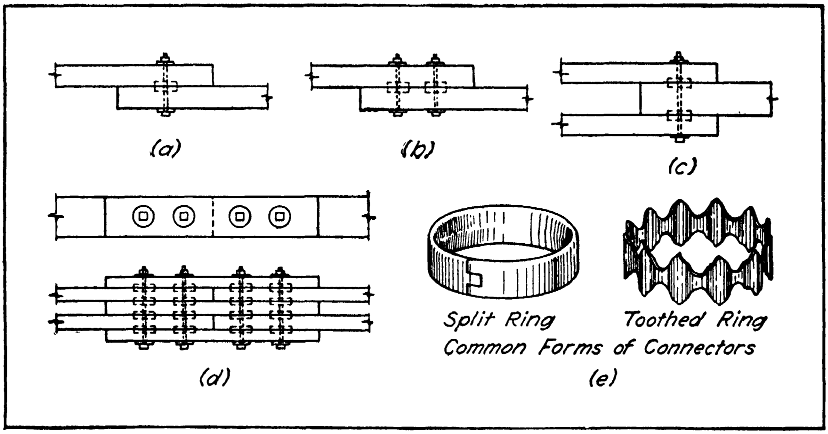


FIG. 130. Joints in Wood Members Using Connectors

In the *tenon-bar splice* shown in Fig. 129*i*, steel bars take the place of fish plates. The bars which pass through the timbers are rectangular in section and are designed as beams. The bearing area of the side of the bar must be sufficient to keep the bearing stresses against the timber within the allowable value and the hole for the bar must be located far enough from the spliced end so that it will not shear the timber between the bar and the end.

Tension members are commonly built up of several planks bolted or nailed together. These may be spliced by *staggering* the joints, as shown in Fig. 129*j*.

In all forms of joints the effect of the shrinkage of the timber may be quite serious. Joints which fit perfectly, when made, may open and cause a redistribution of stress which the joint is not capable of carry-

ing. This possibility should be kept in mind in design and construction and in selecting the type of joint. Joints using modern connectors are shown in Fig. 130. They are not seriously affected by shrinkage and are easily made.

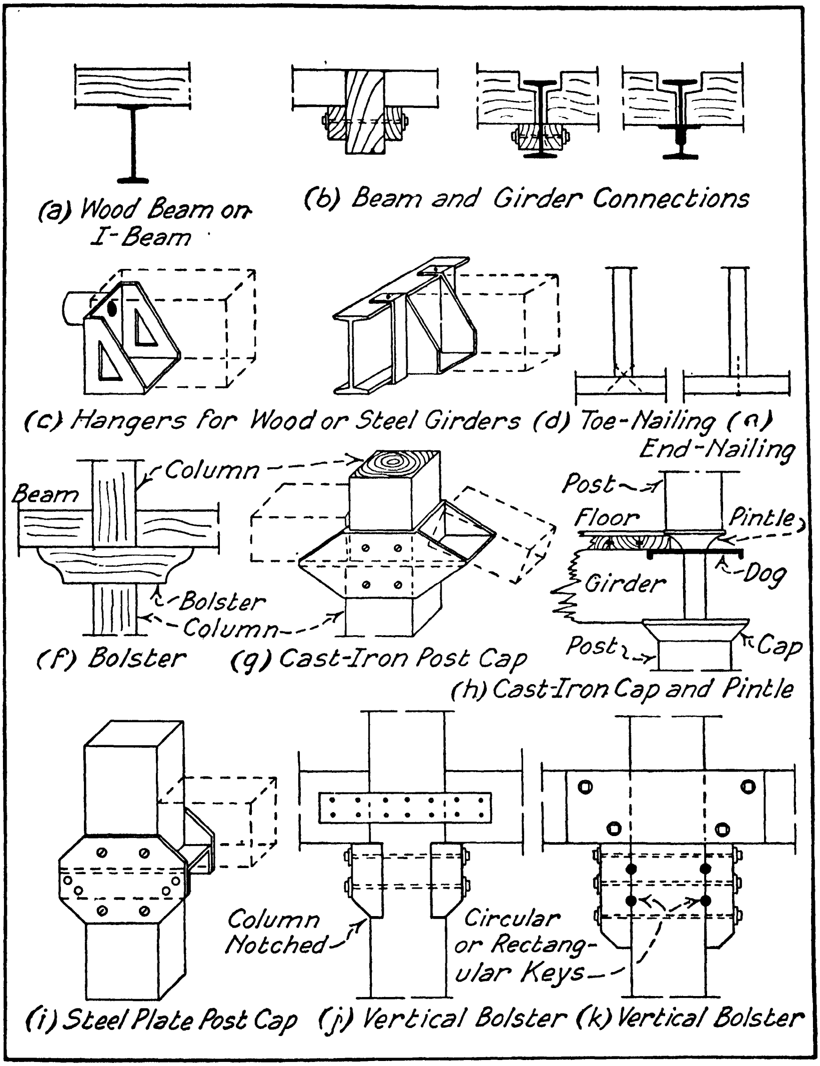


FIG. 131. Timber Beam, Girder, and Column Connections

Beams and Girder Connections. Timber beams or joists may rest on top of timber or steel girders, as shown in Fig. 131*a*; they may be supported on wood strips or shelf angles bolted to the sides of timber or steel girders, as shown in Fig. 131*b*; they may be supported on timber or steel girders by cast-iron or steel hangers, as shown in Fig. 131*c*; or, in light construction, the joists may be *toe-nailed* into timber girders, as shown in Fig. 131*d*, or *end-nailed*, as shown in Fig. 131*e*. For other details see Figs. 138 and 139.

The tops of the wood beams in Fig. 131*b* must be placed far enough above the top of the steel girder to allow for shrinkage or the floor will be uneven at this point.

Connection of Beams and Girders to Columns. Timber girders may be supported at timber columns by using a hardwood *bolster*, as shown in Fig. 131*f*; a cast-iron *post cap*, as shown in Fig. 131*g*; a malleable cast-iron post cap with a *pintle*, as shown in Fig. 131*h*; or a post cap formed of steel plates, as shown in Fig. 131*i*. The detail shown in Fig. 131*j* provides vertical bolster blocks set in notches in the side of the column and held in position by bolts. The notches may be replaced by circular or rectangular keys, as shown in Fig. 131*k*. These details are much superior to the horizontal bolsters shown in Fig. 131*f*, for the bearing is on the end of the grain instead of the side and the effect of shrinkage is less. Caps designed to carry a girder on one side of a column are called *one-way caps*; those designed to carry girders on two opposite sides of a column are called *two-way caps*; and those which carry girders on all four sides are called *four-way caps*. For other details see Figs. 138 and 139.

It is usually desirable to use a post cap of such design that a girder which has burned in two will be released when falling and avoid pulling the entire column down. The caps shown in Fig. 131*g*, *h*, and *i* are of this type. The ends of girders may be tied together at the columns by *dogs* made of steel bars and shaped as shown in Fig. 131*h*; by steel straps held in place by spikes or lag screws driven through holes provided in the straps, as shown in Fig. 131*j*; or by wood planks held in place with bolts, as shown in Fig. 131*k*. Some forms of post caps are so designed that ties are not required, provision being made in the caps for the insertion of bolts or lag screws to hold the girders in place.

Unprotected metal post caps are the most vulnerable feature in slow-burning construction from the standpoint of fire resistance. The cast-iron cap and pintle is superior to the steel-plate cap from this point of view. Wood bolsters are usually permitted only for the support of roof girders.

Wall Supports for Beams and Girders. Light timber joists are built into masonry walls, as shown in Fig. 132*a*, with ties placed at in-

tervals of not over 6 ft. The ends of the joists are cut at an angle so that, in case of fire, they may fall without disturbing the walls.

If the ends of heavy timber girders are built into masonry walls without allowing a space at the sides and top for ventilation, dry rot will be quite certain to result, causing the ends of the girders to rot off.

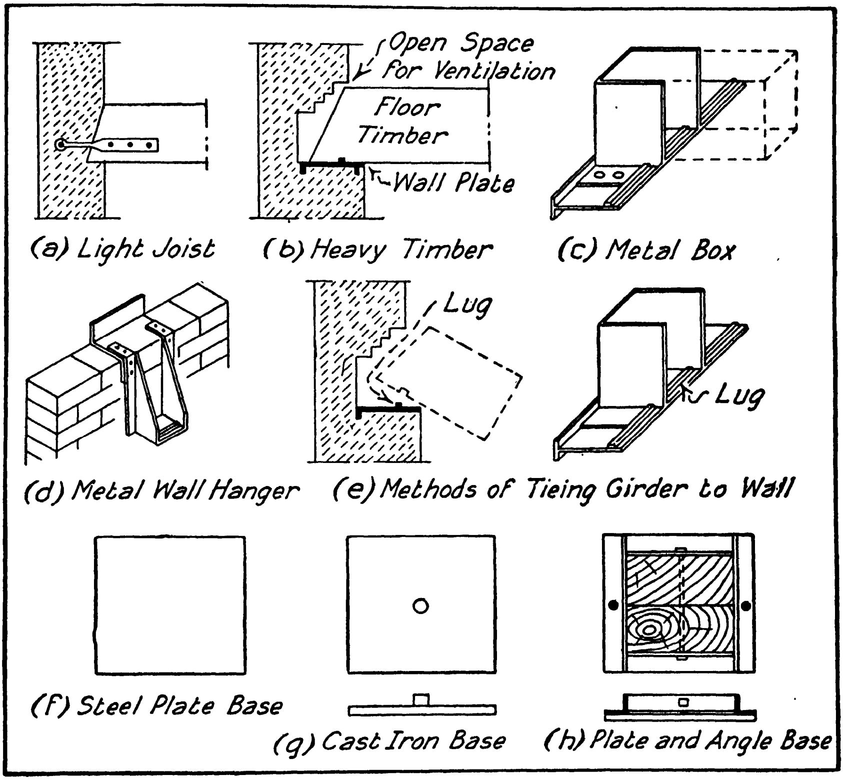


FIG. 132. Wall Supports, Anchors, and Column Bases

As explained on page 55, dry rot results from moisture which is in wood when it is placed and cannot escape. To avoid this, the construction shown in Fig. 132*b* may be used; a special metal box shown in Fig. 132*c* may be provided; or a metal wall hanger shown in Fig. 132*d* may be installed. Various methods have been devised to tie the girder to the wall and still enable it to be released in case of failure due to fire. See Fig. 132*e*.

Column Bases. Wood columns should not rest directly on masonry footings for moisture may be transferred from the footing to the column causing the end of the column to rot or termites may enter at this point. Column bases are used. They may be steel plates as

shown in Fig. 132*f*; cast-iron bases as shown in Fig. 132*g*; or steel bases consisting of a plate and angles riveted together as shown in Fig. 132*h*. Column bases have the additional function of distributing the column load over a larger area on the footing. See also Figs. 138 and 139. Termite shields similar to that in Fig. 9 may be used.

Frame Construction. In the construction of frame houses, and other small frame buildings, the braced frame, the balloon frame, or the platform frame may be used. It is not considered good practice to make such buildings over three stories high.

The *braced frame* is illustrated in Fig. 133 and consists of heavy sills, corner posts, plates, and girts which are framed together and given lateral rigidity by heavy *knee-braces* at the corners, in the plane of the walls. The studs are 2 by 4 in. or 2 by 6 in., and usually extend one story, where they frame into the *girt*. The floor joists are 2 in. thick, and vary in depth from 8 to 12 in. Above the first floor, the joists rest on the girts. The rafters are 2 by 6 in. or 2 by 8 in. and are notched to secure bearing on the plate at the top of the studs. *Cross bridging* spaced not over 8 ft. center to center is used to stiffen the floor and to distribute concentrated loads over several joists. The *wall sheathing* may be placed diagonally or horizontally, the former being preferred. The sub-floors are always placed diagonally. The partition studs in the second story do not rest on the sub-floor but pass down through the floor and rest on the top plate of the first-story studs. The reasons for this construction are given in Art. 37. The figure shows a hip roof, but the gable roof shown in Fig. 134 may be used.

The *balloon frame*, illustrated in Fig. 134, does not have the heavy corner posts, girts, etc., used in the braced frame; the studs are 2 by 4 in. or 2 by 6 in., continuous for two stories. The floor joists are 2 in. thick and 8 to 12 in. deep. The ends of the floor joists above the first floor are carried on a *ribbon* or *ledger board* which may be as light as 1 by 6 in. but is preferably 2 by 6 in. This ribbon should be notched into the studding. Cross bridging is used as in the braced frame. The rafters are notched so as to secure bearing on the plate at the top of the studs. The partition studs in the second story do not rest on the sub-floor but on the top plate of the first-story studs. See Art. 37. The balloon frame is used much more than the braced frame, on account of the smaller amount of labor involved. The figure shows the type of framing for a gable roof, but a hip roof, as shown in Fig. 133, may be used.

The braced frame and the balloon frame have not been so standardized that there are definite distinctions between the two types in all essential features. The braced frame was so named because of the heavy corner braces which extended diagonally from the heavy

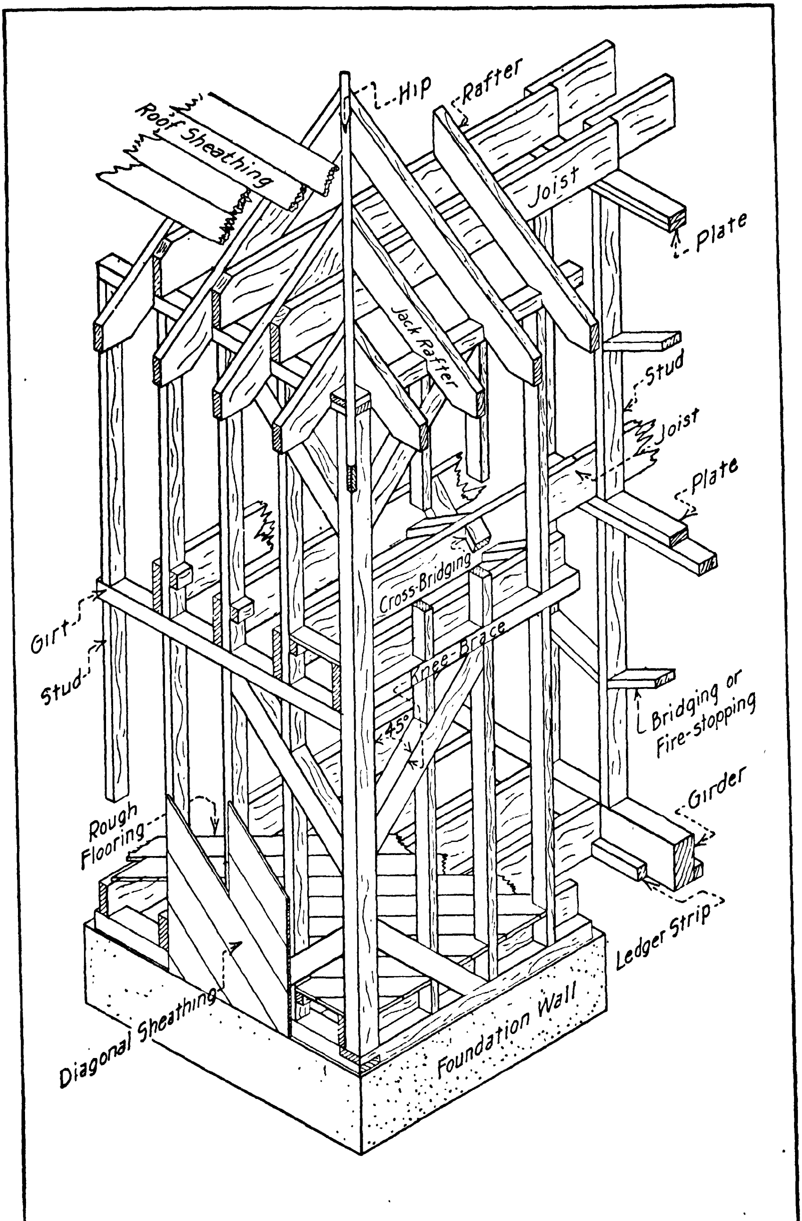


Fig. 133. Braced-Frame Construction

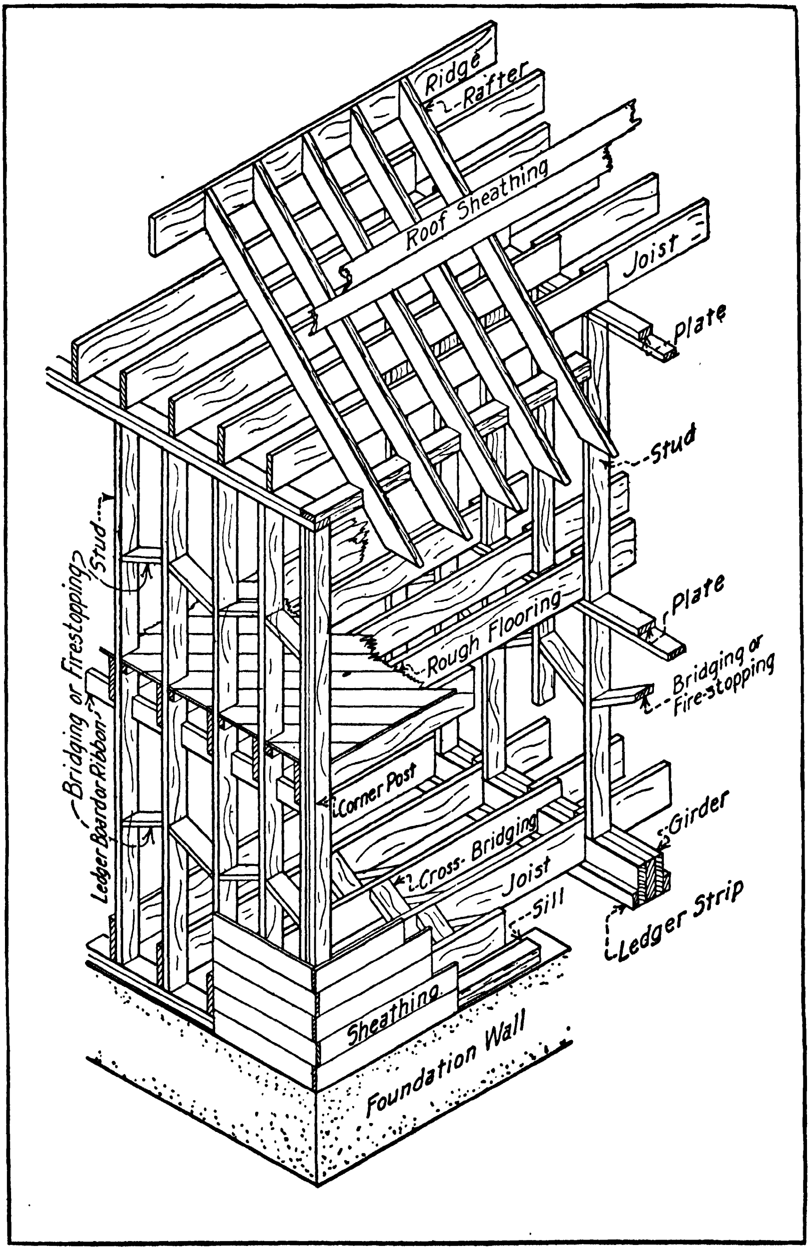


FIG. 134. Balloon-Frame Construction

girt to the corner posts, but it is considered good practice to use 2 by 4-in. braces cut in between the studs. The corner posts of the braced frame should probably be dimension timbers such as 4 by 4 in. or 6 by 6 in., but it is acceptable construction to build these posts up of 2-in. material, as in the balloon frame. The balloon frame is often corner-braced just as substantially as the braced frame. Either type may have diagonal or horizontal sheathing, but diagonal sheathing gives much greater lateral strength and rigidity with little, if any, increase in cost. There is always an essential difference in the two types of frame, however; the outside wall studs of the braced frame extend through one story only and frame into a heavy girt on which the second-floor joists rest, while the outside wall studs of the balloon frame extend through two stories and the second-floor joists are supported on a light member — a ribbon or ledger board — notched into the studs about an inch.

In both types of construction all openings, on the inside of walls, partitions, and floors, which would permit fire to pass from one part of the building to another should be firestopped with some incombustible material. Lath and plaster surfaces are not considered effective firestops. The spaces between joists and over the top plate of walls and partitions should be firestopped. Solid bridging should be provided between the studs at their midheight to obstruct the upward passage of fire between the studs and behind the plaster. See Fig. 103. Termite shields, as shown in Fig. 9, should always be used. If sub-floors are laid before the roofing is placed, and they usually are, the joints between boards should be left open about $\frac{1}{4}$ in. to allow for swelling if they get wet, or every tenth board should be left out until the roofing is on.

The *platform frame* is illustrated in Fig. 104 and explained in Art. 37.

The braced frame is sometimes called the *drop-girt frame*, and the platform frame is sometimes called the *western frame*.

For a discussion of frame walls and partitions see Art. 37.

Ordinary Construction. In ordinary construction the walls are of masonry, the interior framing is the same as in the braced frame or balloon frame, but metal beams and columns are sometimes used in parts of the building. See the definition of ordinary construction under Classification of Buildings in Art. 2.

A typical cross-section of a two-story dwelling of ordinary construction with brick walls is shown in Fig. 135, and of a two-story business building of ordinary construction with brick walls in Fig. 136. These buildings illustrate the principles of construction which have been explained under the appropriate headings. Some of the more important features are:

1. The outside walls in the dwelling house are 8 in. thick for the second story and 12 in. thick for the first story and basement, which corresponds to the usual practice. The recommendations of the Building Code Committee of the Department of Commerce would permit an 8-in. wall to be used for the first story as well as for the second story if the allowable unit stresses are not exceeded, and they probably would not be.

The outside walls of the business building are 12 in. thick for the first and second stories and 16 in. thick for the basement, as required.

In both buildings where the walls change in thickness, the thicker wall is extended to the tops of the floor joists.

Cavity walls 10 and 14 in. thick, as described in Art. 25, could be substituted for the 8- and 12-in. solid walls.

2. The story heights are low enough in all cases so that the walls receive the required lateral support.

3. On the business building the parapet wall satisfies the minimum height requirement of 32 in. and the maximum height requirement of not over four times its thickness. It satisfies the minimum thickness requirement of 12 in. and the requirement that it be as thick as the wall below. It has the desirable feature of a coping which drains toward the roof.

4. The outside walls in both buildings are furred and fire stops are provided at the floors to cut off the air space behind the furring at each floor. If cavity walls are used, furring is unnecessary.

5. A fire stop is provided to cut off the cornice on the dwelling house.

6. The interior bearing wall in the basement is 8 in. thick, which satisfies the recommendations.

7. The studs of the second-story partitions in both buildings bear on the top plate of the stud partition below. This is to reduce settlement due to side shrinkage. This type of construction is greatly superior to that which rests the studs on a sole plate placed on top of the sub-floor.

8. Fire stops are provided between the studs where they pass through the second floor and between the joists over the plate at the attic floor.

9. Solid bridging is provided at the midheight of all stud partitions. This bridging stiffens the studs and acts as a fire stop. The horizontal bridging is staggered to facilitate nailing. In some cases horizontal bridging is shown, and in others inclined bridging. The latter gives more lateral resistance to the partition as a whole.

10. The top plates of all stud partitions are doubled and are made of the same size material as the studs.

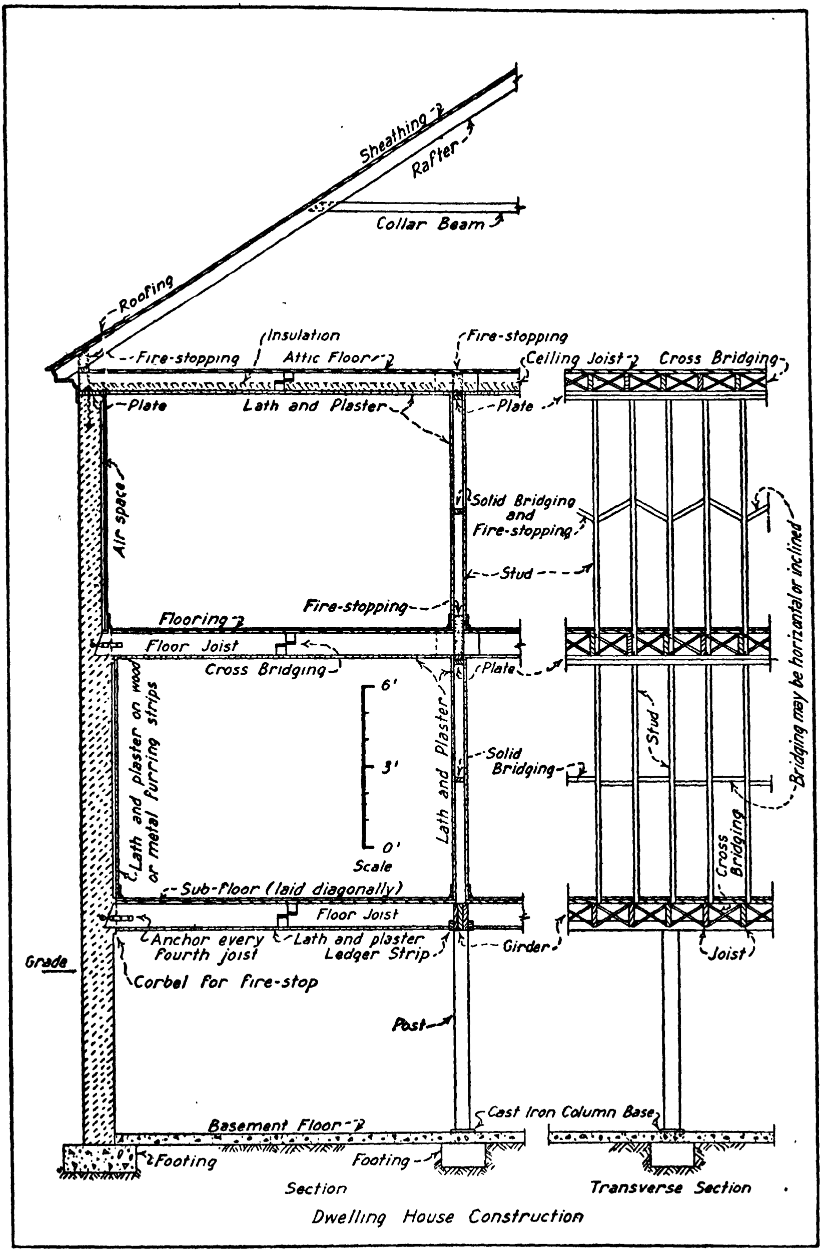


FIG. 135. Ordinary Construction for Dwelling House

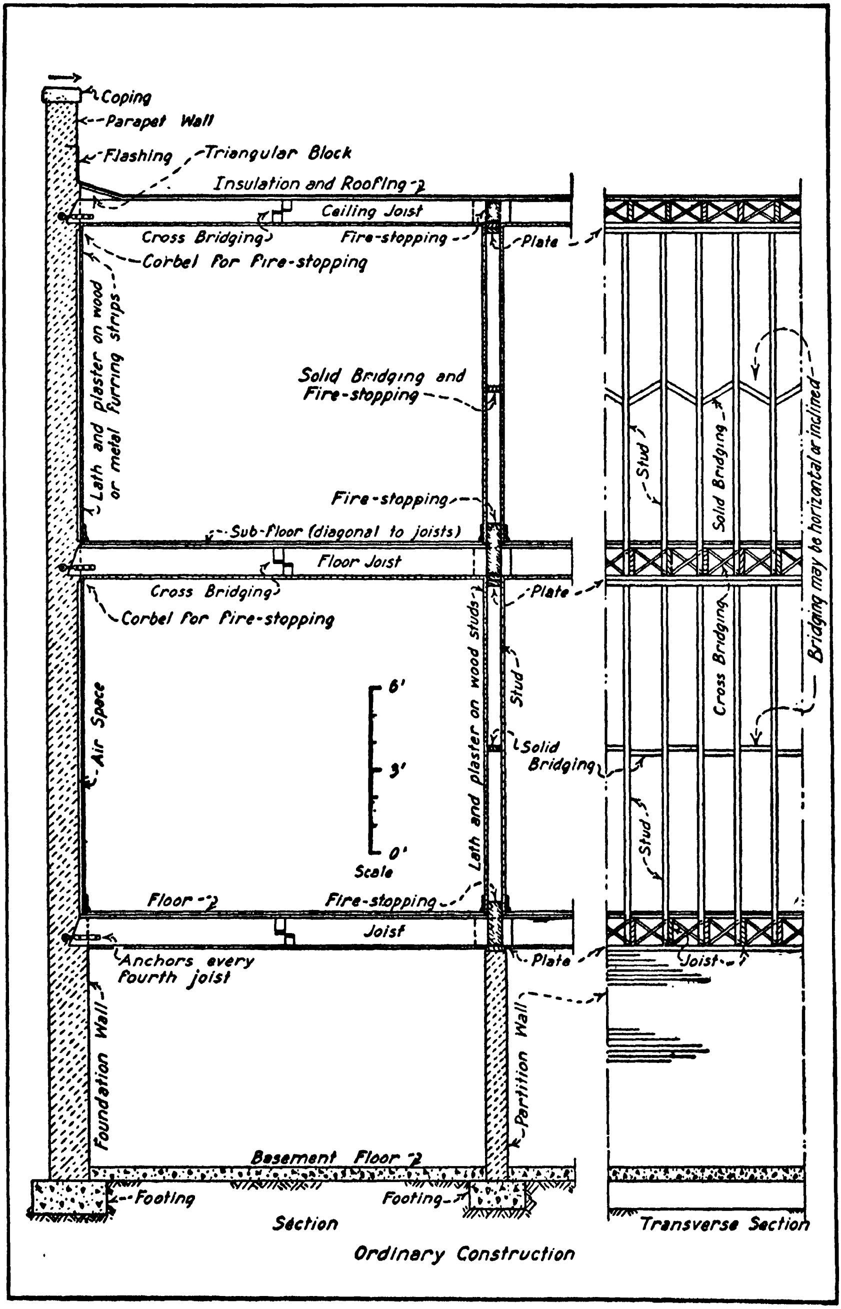


FIG. 136. Ordinary Construction for Light Commercial Building

11. The posts in the basement of the dwelling house bear on independent footings and not on the basement floor. They rest on cast-iron plates which prevent the transmission of moisture from the ground through the footing and into the end of the post. This avoids the danger of rotting and termites. It is sometimes required that the top of this plate be 3 in. above the floor.

12. The floor joists bear 4 in. on masonry walls. The ends which bear on the walls are beveled so that they will release in case of fire.

13. The joists are anchored to the masonry walls by metal anchors placed near the bottom of the joists and located on every fourth joist.

14. Cross bridging is provided between all joists, and since the spans are all less than 16 ft. only one row is required.

15. One end of the first-floor joists in the dwelling house is notched to rest on a ledger strip spiked to the side of the built-up girder. The joists are toe-nailed into the girder. The settlement due to side shrinkage is much less using this type of construction than it would be if the joists rested on top of the girder.

16. Diagonal sub-floors are provided in both buildings. These are much superior to the sub-floor placed at right angles to the floor. The diagonal floors facilitate the laying of the finished floor which should always be laid at right angles to the joists and should be nailed through the sub-floor and into the joists.

17. Solid sheathing is provided on the roof of the dwelling.

18. Insulation, as described in Art. 81, is provided above the ceiling of the second story. This makes the dead-air space commonly provided under flat roofs unnecessary.

19. An attic floor is provided in the dwelling for convenience, insulation, and to increase the fire resistance.

Slow-Burning or Mill Construction. Slow-burning or mill construction, as defined in Art. 2, has the following essential characteristics:*

1. Outside walls of masonry.

2. Heavy timber interior framing arranged with smooth flat surfaces and a minimum number of corners.

3. No concealed spaces which can not be readily reached in case of fire.

4. Separation of building into units by incombustible walls and partitions provided with doors which will automatically close in case of fire.

5. Separation of floors by enclosing stairways and elevator shafts in fireproof towers or if this is not possible, by encasing them.

* Arranged from publications of the National Lumber Manufacturers' Association.

6. Avoiding openings in floors for the passage of belts, etc., or by protecting such openings by automatic hatchways or otherwise so as to prevent the passage of fire and water from floor to floor.

7. The installation of an automatic sprinkler system is desirable.

8. The waterproofing of floors and providing drainage so that water will not leak through to the floor below.

9. Protection of ceilings over highly inflammable stocks with a fire-retardant material.

The National Fire Protection Association has adopted the term slow-burning, heavy timber construction for buildings of this class and divides such buildings into three types:

Girder Type. This type includes buildings with floors of heavy planks laid flat upon large timber girders which are spaced not less than 8 ft. on centers and supported by wood posts or columns at intervals of not less than 12 ft. This type is commonly called *standard mill construction.*

Beam and Girder Type. This type includes buildings with floors of heavy planks laid flat upon large timber beams spaced not less than 4 ft. on center and supported by large timber girders and wood posts or columns spaced according to sound engineering practice. This type is commonly called *semimill construction.*

Laminated Type. This type includes buildings with floors of heavy planks laid on edge upon large girders spaced not less than 12 ft. on centers and supported by wood posts or columns at intervals preferably not less than 16 ft. This type is commonly called *mill construction with laminated floors.*

The substitution of protected steel or reinforced-concrete framing for portions of the structure is not considered as altering the type. The floors of all of the above types are provided with a top floor to take the wear and give a finished surface.

A typical cross-section of a slow-burning, heavy timber construction, girder-type building is shown in Fig. 137.* The essential features of this type of construction are:

1. Heavy masonry walls with 3-ft. parapet. Coping slopes draining to roof.

2. Heavy timber girders with minimum size of 6 in. by 10 in.

3. Wall end of girder ventilated on sides and top to prevent dry rot and resting on metal wall plate which anchors girder but would release it if it burned in two and fell.

* Arranged from publications of the National Lumber Manufacturers' Association.

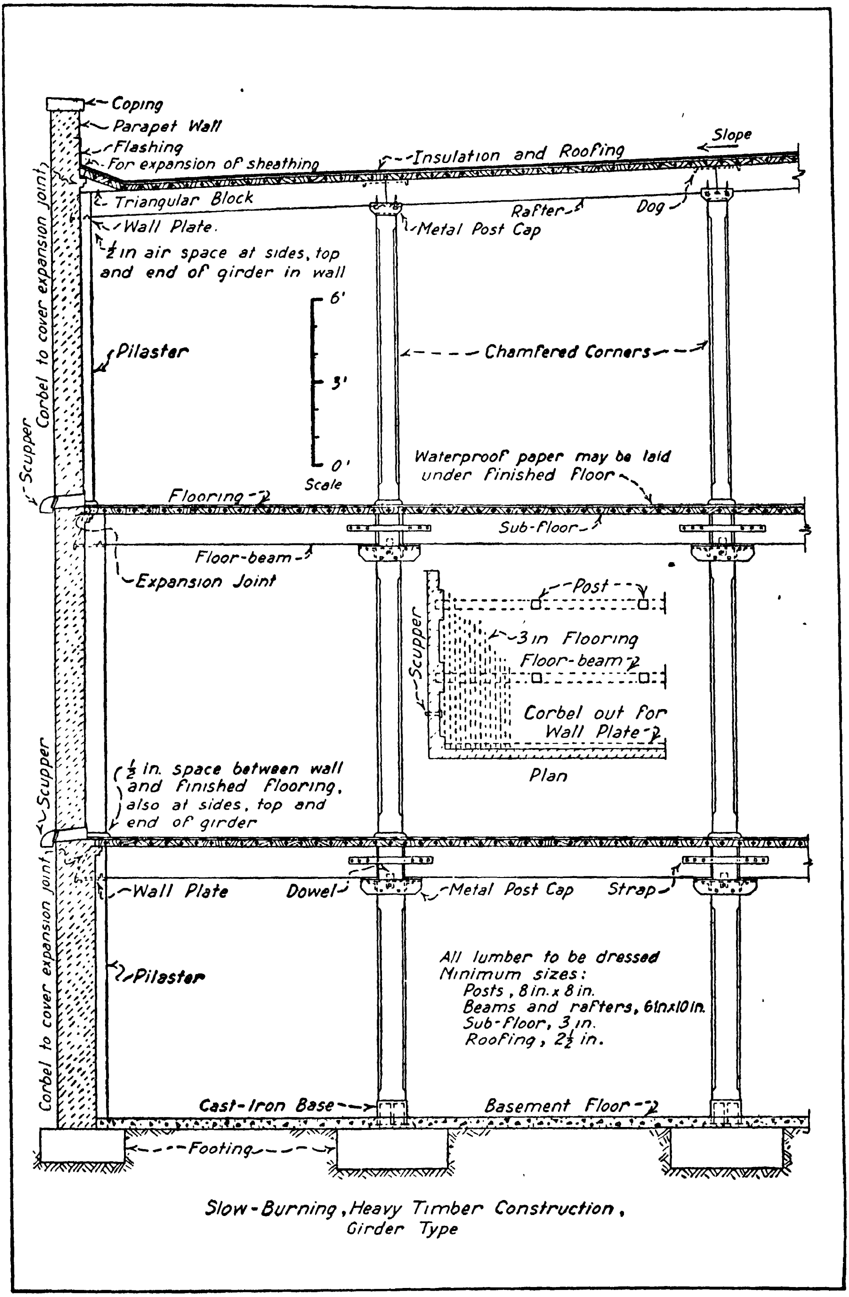


FIG. 137. Slow-Burning, Heavy Timber Construction, Girder Type

4. Column end of girders supported on columns by metal post caps which permit columns of story above to pass the end of the girders.

5. Lines of girders tied across columns by metal straps except the roof girders which are tied by metal dogs.

6. Heavy timber columns with minimum size of 8 in. by 8 in.

7. Corners of columns chamfered.

8. Columns of each story pass ends of girders and rest on column below. Columns held in line by dowels in caps.

9. Bottom of column rests on cast-iron base which distributes load on footing and prevents ground moisture from entering end of column and causing rot. End of column is raised well above the basement floor.

10. Heavy wood sub-floor with minimum thickness of 3 in.

11. Floor planks jointed by a loose tongue or spline which is preferable to matching for heavy floor. Heavy roof sheathing with a minimum thickness of 2½ in.

12. Expansion joint left between wall and sub-flooring and sheathing and between wall and finished flooring to permit swelling without pushing wall out. Expansion joint covered on lower side by corbel in wall and on upper side by molding nailed to wall but not to the floor.

13. Roof insulated to reduce heat losses in cold weather and to make building cooler in hot weather.

14. Finished floor placed on sub-floor to take wear and improve appearance.

15. Waterproof paper placed under finished floor if desired.

16. Scuppers provided in outside walls and in interior where necessary to drain floor of water from automatic sprinklers or fire hose in case of fire.

17. All lumber is dressed to increase its fire resistance. Oil paint or varnish not used.

The details used in slow-burning, heavy timber construction of the girder type and of the laminated type are shown in Fig. 138.* In addition to the features mentioned in the discussion of Fig. 137 the following should be noted:

1. The cast-iron post cap and pintle. The function of the pintle is to carry the column load to the column below without resting the column on the girders. If the columns rested on the girders and the girders burned in two at any floor the columns above that floor would be pulled over and a general failure would result. Pintles are not often used.

2. The laminated floor consisting of planks placed on edge and spiked together forms an excellent floor and makes longer spans possible.

*** Arranged from publications of the National Lumber Manufacturers' Association.**

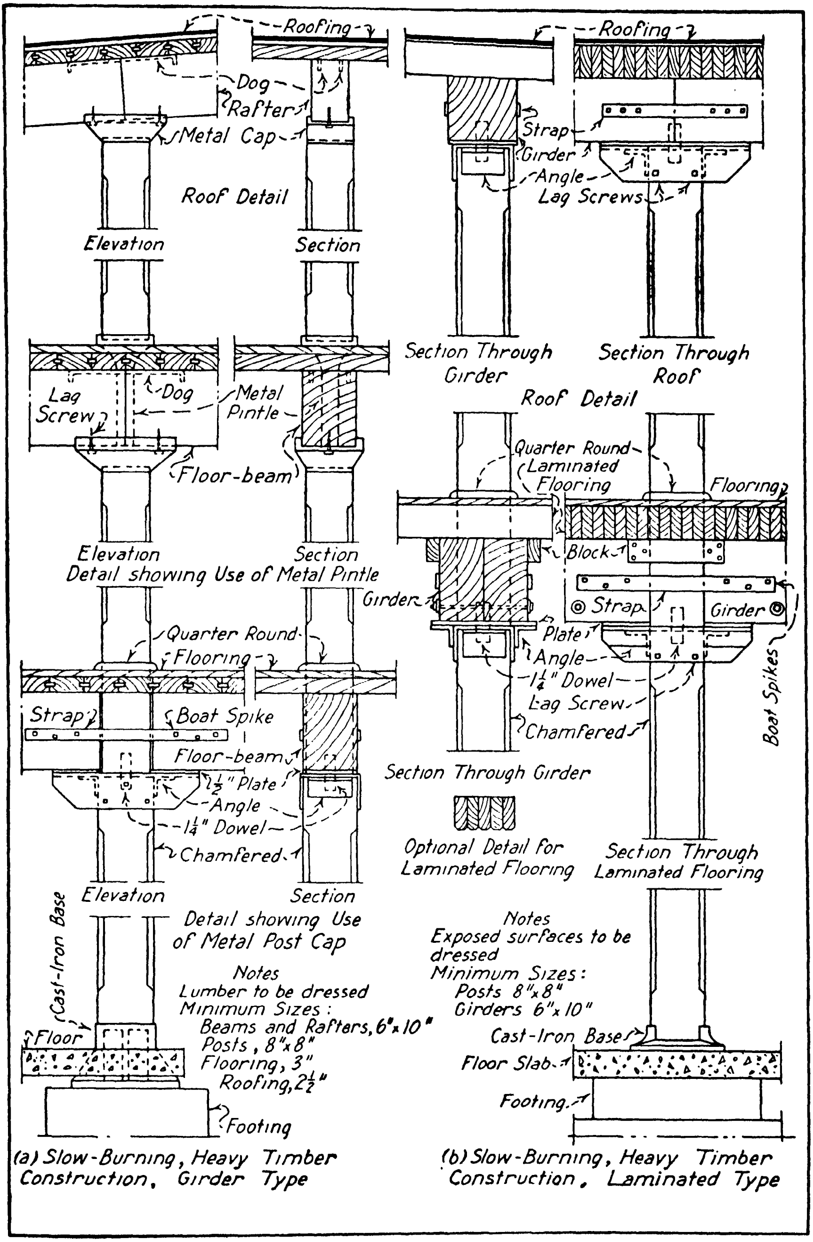


FIG. 138. Details of Slow-Burning Construction

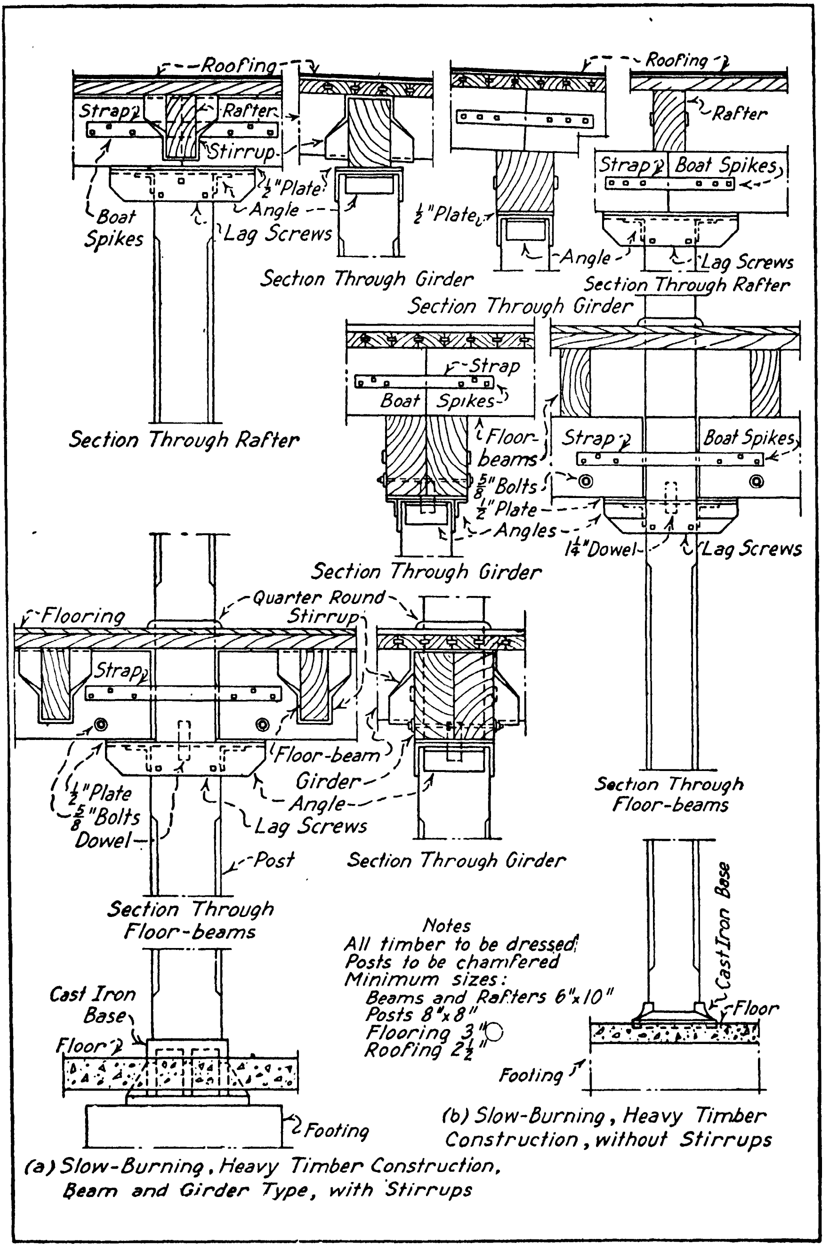


FIG. 139. Details of Slow-Burning Construction

The corners of these planks are often chamfered. To permit expansion and contraction, the laminated floor is not fastened to the girders on which it rests.

3. Owing to the longer spans of the laminated floors, heavier floor girders may be required in this type of construction. A girder consisting of two timbers placed side by side and bolted together is shown.

4. Blocks are provided to carry the ends of the flooring over the gap between the ends of the girders framing into the two sides of the columns when the built-up cap is used. These are not necessary when the pintle is used because the ends of the girders then come together.

5. Built-up caps are fastened to the columns with lag screws. Cast-iron caps are fastened to the girders with lag screws.

The details used in slow-burning, heavy timber construction of the beam and girder type are shown in Fig. 139. Many of the details mentioned in discussing Fig. 138 apply also to this type of construction. The construction feature peculiar to this type is the use of beams to carry the floor planks. These beams are spaced 4 to 10 ft. apart and are supported by the girders either by resting their ends on top of the girders or by supporting the ends in metal stirrups. The latter method gives more headroom and is more compact, but the metal stirrups are a point of weakness in case of fire.

REFERENCES

1. Forest Products Laboratory: "Wood Handbook," U. S. Department of Agriculture, 1935.

2. JACOBY, H. S., and ROLAND P. DAVIS: "Timber Design and Construction," 2nd Ed., John Wiley & Sons, 1930.

3. National Lumber Manufacturers' Association: "Manual of Timber Connector Construction," 1939.

4. National Committee on Wood Utilization and Forest Products Laboratory: "Modern Connectors for Timber Construction," 1933.

5. Timber Engineering Company: "Modern Timber Roof Trusses," Washington, D. C., 1940.

6. PERKINS, N. S.: "Timber Roof Truss of 111-Ft. Span Placed by Crane after Assembly," *Engineering News-Record,* Nov. 5, 1936.

7. WILSON, T. R. C.: "The Glued-Laminated Wooden Arch," Technical Bulletin 691, U. S. Department of Agriculture, 1939.

8. Federal Board for Vocational Education and the National Committee on Wood Utilization: "Light Frame Construction," Bulletin 145.

9. HOLTMAN, DUDLEY F.: "Wood Construction," McGraw-Hill Book Co., 1929.

10. DEWELL, HENRY D.: "Timber Framing," Dewey Publishing Co., 1917.

11. Various Publications of National Lumber Manufacturers' Association, Washington, D. C.

CHAPTER VII

STEEL CONSTRUCTION

ARTICLE 43. ROLLED STEEL SECTIONS

Types of Rolled Sections. The various types of rolled sections used alone or riveted or welded together to form columns, beams, girders, trusses, and other structural units are shown in Fig. 140. The parts of these sections are designated as *flanges*, *webs*, and *stems*, as indicated on the figure.

The *wide-flange sections*, called WF sections, or H sections for some sizes, vary in depth and weight per foot from a maximum of 36 in. and 300 lb. to a minimum of 4 in. and 7½ lb. The inner and outer faces of these sections either are parallel or the inner face may have a slope of 1 to 20, depending upon the one who manufactures. There are two general forms of wide-flange sections. The sections which are relatively deep and narrow, shown in Fig. 140*a*, are more suitable for beams and girders, while those which are more nearly square, shown in Fig. 140*b*, are desirable for column sections.

The *American standard beams*, called I beams, shown in Fig. 140*c*, vary in depth and in weight per foot from a maximum of 24 in. and 120 lb. to a minimum of 3 in. and 5.7 lb. The inner face of the flanges of these sections has a slope of 1 in 6.

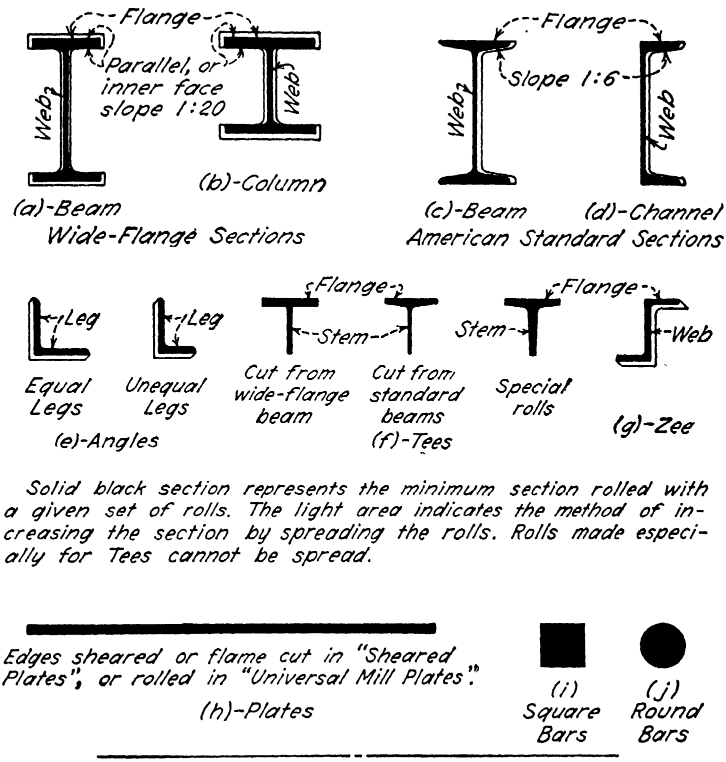
The *American standard channels*, called channels, shown in Fig. 140*d*, vary in depth and in weight per foot from a maximum of 18 in. and 58 lb. to a minimum of 3 in. and 4.1 lb. The inner face of the flanges of these sections has a slope of 1 in 6.

Angles are divided into those with *equal legs* and those with *unequal legs*, as shown in Fig. 140*e*. Equal-leg angles vary in size, thickness, and weight per foot from a maximum of 8 by 8 by 1⅛ in. and 56.9 lb. to 1 by 1 by ⅛ in. and 0.80 lb. Unequal-leg angles vary in size from 8 by by 6 by 1⅛ in. and 49.3 lb. to 1¾ by 1¼ by ⅛ in. and 1.23 lb.

Tees, as shown in Fig. 140*f*, are commonly made by splitting the webs of wide-flange or American standard beam sections and so are available in sizes according to the sections from which they are cut. These are called *structural tees* and are the ones commonly used in structural framing. Other tees are available in depths from 6½ in. to 2 in.

Zees, as shown in Fig. 140*g*, are rarely used as structural framing members. They vary in depth from 6 in. to 3 in.

Plates, as illustrated in Fig. 140*h*, are one class of flat rolled steel. If the width is 6 in. or less, they are classed as *bars*, and if over 6 in. as *plates*. Plates which are over 2 in. thick are called *bearing plates*



Wide-Flange Sections	24 WF 74	Tees	T3X3X6.7
American Standard Beams	15I42.9	Zees	Z6X3½X15.7
American Standard Channels	9 ⊔ 13.4	Plates	18X½
Equal Leg Angles	∠3X3X¼	Square Bars	1⌀
Unequal Leg Angles	∠7X4X½	Round Bars	1φ
Structural Tees	ST5 WF 10.5	Flat Bars	2½X¼

STANDARD DESIGNATIONS FOR USE ON DRAWINGS
American Institute of Steel Construction

FIG. 140. Types and Designations of Rolled Steel Sections

because they are used almost entirely for bearing plates for the ends of columns and girders. Plates are available in thicknesses from $\frac{1}{4}$ in. to 2 in., and widths from 6 in. to $15\frac{1}{2}$ ft. Bearing plates are available in sizes up to 56 in., and thicknesses up to 8 in. For thicknesses up to 2 in. plates are sufficiently smooth and flat to use as bearing plates to receive accurately finished *milled* ends of columns, and plates up to 4 in. can be straightened in presses to the necessary flatness. The top surfaces of plates thicker than 4 in. should be planed over a sufficient area to receive milled-column sections if the plates are grouted on concrete foundations, but both faces should be planed if they rest on steel. Plates on which the edges are rolled when the plates are being rolled are called *universal mill* plates. Their width is usually limited to 30 in.

Square and round bars, as shown in Fig. 140*i* and *j*, are used for ties, lateral bracing, and hangers in structural-steel framing, and very extensively as reinforcing in reinforced-concrete structures. Many sizes are available.

The various weights which are available for the sections, shown in Fig. 140*a* to *g*, are obtained by spreading the rolls which produce the sections. This process adds to the area of the sections, as shown in the figure. It can be seen that the thickness of the flanges, as well as the depth of the wide-flange sections, increases as the rolls are spread, but all the sections in a given series are designated by a single *nominal depth* regardless of the *actual depth.* This increase in the flange thickness is desirable because a given amount of material added to the flanges increases the rigidity of a member much more than the addition of the same amount of material to the web. American standard beams and channel sections of a given depth are increased in weight and cross-sectional area by spreading the rolls in such a manner that all the additional material goes into the web where it is not very effective in increasing the rigidity of the section. The actual depth of all these sections in a given depth series is the same and is equal to the depth by which the series of sections is designated. The spreading of the rolls to increase the thickness of an angle also increases the lengths of the legs, but these increases are not taken into account in designating the size of the angle.

The wide-flange sections and the structural tees made from them are furnished only by the Bethlehem Steel Company or the Carnegie-Illinois Steel Corporation. All other sections are furnished by all mills rolling these products.

Structural-steel sections are manufactured at steel mills. The operation of cutting the various structural sections to the required size,

fastening them together to form columns, girders, trusses, and other structural members, is called *fabrication.* This work is done by fabricating plants. The individual units are shipped to the building site in sizes that can be transported and handled on the job and are placed in position, or *erected.*

The individual sections are fastened together, in both fabrication and erection, by riveting, welding, or bolting, as described in Art. 48.

Designations of Sections. The standard designations for structural-steel sections as adopted by the American Institute of Steel Construction are shown in Fig. 140. The meanings of the various terms are as follows:

For *wide-flange sections*, the 24 is the *nominal depth* in inches; the combined W and F is an abbreviation of wide flange, the 74 is the weight per linear foot in pounds. Wide-flange sections are often designated by giving the nominal depth, the nominal width of flange, and the weight per foot, thus, 24 × 9 WF 74, the W and F being combined.

For *American standard beams*, the 15 is the *actual depth* in inches; the I signifies I beam; and the 42.9 the weight per foot in pounds.

For *American standard channels*, the significance of each expression is the same as for beams except the I is changed to a channel.

For *angles*, the first symbol designates the type of section, is followed by the width of each leg and the thickness in inches.

For *structural tees*, the ST is an abbreviation of the name of the section, the 5 is the nominal depth of the stem in inches and is equal to one-half the nominal depth of the wide-flange section from which the tee was cut; the combined W and F indicates the source of the section; the 10.5 is the weight per linear foot in pounds and is equal to one-half the weight of wide-flange or standard beam sections from which the tee was cut.

For ordinary *tees*, the T indicates the type of section and the numerals indicate the depth and width of flange, in inches, and the weight per linear foot in pounds.

For *zees*, the designation corresponds to that for tees.

For *plates*, the width and thickness in inches are given.

For *square bars*, the size in inches is followed by the special designation for a square bar consisting of a square with a vertical or inclined line drawn through it. This line is often omitted.

For *round bars*, the designation corresponds to that of square bars with a different designation for shape, the square being replaced by a circle.

For *flat bars*, the width in inches is followed by the thickness in inches.

In all cases, the *number of pieces* of a given type, size, and length is shown by a numeral in front of the above designations, and the *length* by a dimension in feet and inches following the designation. For example, 3 - 15I's 42.9 × 12′6″ would indicate three I beams 15 in.

deep, weighing 42.9 lb. per ft. and having a length of 12′6″. The inch and pound symbols are not used in these standard designations except in the length, but they are commonly used elsewhere.

ARTICLE 44. STEEL COLUMNS

Types of Column Sections. Structural-steel columns may consist of a single piece, such as the H section shown in Fig. 141*a*, or they may be *built up* of various sections, as shown in Fig. 141*b* to *o*. The individual sections are usually riveted together, as shown in Fig. 141*p*, to form the built-up sections. The small diagonal bars which fasten together the two parts of the sections shown in Fig. 141*q* are called *lacing bars* or *lacing*. They are indicated on cross-sections by dotted lines, as shown in Fig. 141*e*, *f*, and *g*. Lacing bars are rarely used in buildings at the present time.

H-Section Columns. The most commonly used column section is the H section shown in Fig. 141*a* with nominal depths of 4 to 14 in. Various weights are available for each nominal depth, but it should be noted again that the spreading of the rolls to produce sections with several areas of the same nominal depth increases the actual depths of the sections. For example, the wide-flange section which has a nominal depth of 14 in. and weighs 87 lb. per ft. is the minimum section rolled with the 14-in. rolls. It has an actual depth of 14 in. and a flange thickness of 0.688 in.; while the maximum 14-in. section, which weighs 426 lb. per ft., has an actual depth of 18.69 in. and a flange thickness of 3.033. The difference between the thicknesses of the flanges of the two sections is $3.033 - 0.685 = 2.348$. Multiplying this by 2 and adding to the depth of the lighter section the value $4.69 + 14.00 = 18.69$ in. is obtained, which is the depth of the heavier section.

Cover-Plated H-Section Columns. Heavier column sections than a maximum wide-flange section can be obtained by riveting *cover* or *flange plates* to such a section, as shown in Fig. 141*b*. There is a special 14-in. *core section* weighing 320 lb. per ft. to use for this purpose. It has a relatively thick web as required to support adequately the thick flanges formed by cover plates. Cover plates, each with thicknesses of $\frac{3}{4}$ in. or over, might be riveted to each flange to give a total thickness 3 or 4 in. or even more for each flange. This core section with cover plates on each flange 24 in. wide and with a total thickness of $3\frac{1}{2}$ in. would have an allowable load of more than 4,000,000 lb. Plates thicker than $\frac{3}{4}$ in. are not often used.

Plate and Angle Columns. Columns are built up of four angles and a web plate, as shown in Fig. 141*c*, with cover plates also, as shown in Fig. 141*d*. Columns of almost any size desired can be built up in

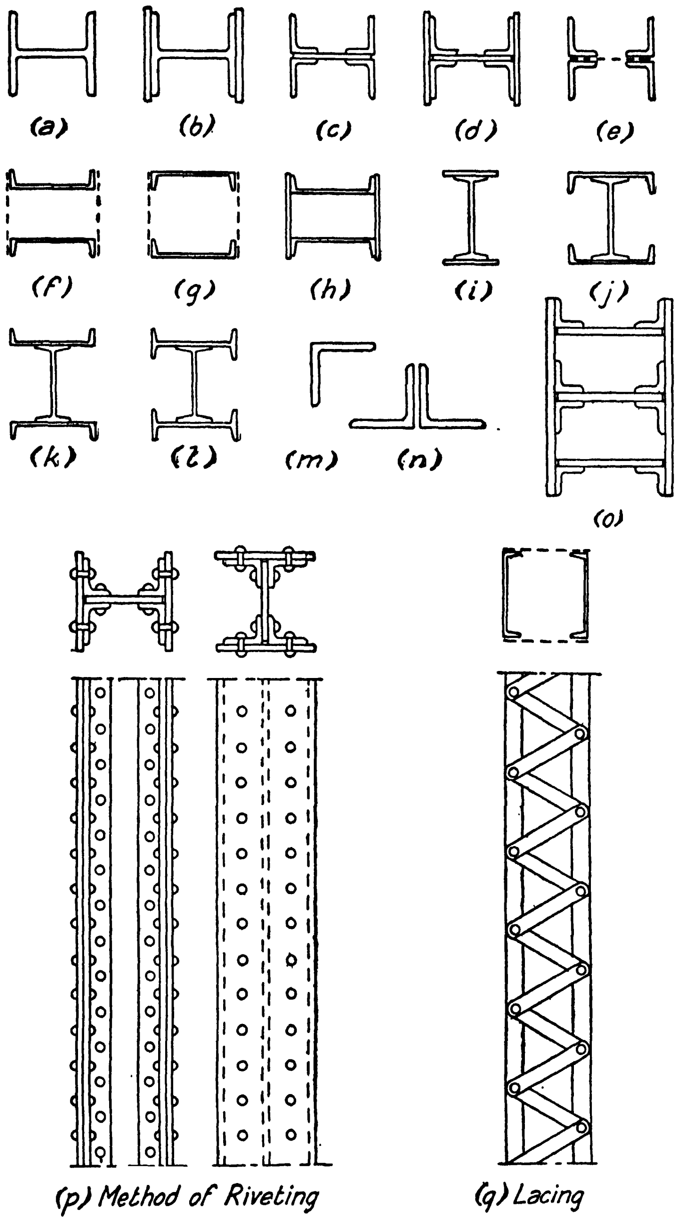


FIG. 141. Steel Columns

this way. For example, a section with four 8- by 8- by $1\frac{1}{8}$-in. angles, a 16-in. web with a total thickness of $1\frac{3}{8}$ in., cover plates 24 in. wide and with a total thickness of $3\frac{1}{2}$ in. on each flange would have an allowable load of over 4,000,000 lb. which is about the same as that of the section given in the preceding paragraph.

Other Types. The other types of sections shown in Fig. 141 are not used to any extent, except the angle sections which may be used for very light corner columns or wherever their form is advantageous. However, these angle sections are extensively used as members of roof trusses.

ARTICLE 45. STEEL BEAMS

The general term *beam* may include various flexural members such as beams, girders, joists, lintels, purlins, and rafters, as explained in Art. 33, which are given specific names because of the manner in which they are used.

Types of Beams. The cross-sections of various types of beams are shown in Fig. 142. The wide-flange section shown in Fig. 142*a* and the American standard I beams shown in Fig. 142*b* are the most commonly used sections. They are available in a great variety of sizes. The channel shown in Fig. 142*c* is extensively used for roof purlins. The wide-flange section or the I beam may be provided with *cover* or *flange plates,* as shown in Fig. 142*d*. Beams may be built up of plates and angles, as shown in Fig. 142*e* and *f* to obtain almost any size desired. The sections shown in Fig. 142*g* and *h* are used occasionally.

Separators. In Fig. 142*i* and *j*, two beams have been fastened together with *separators* to hold them in position and to make them act more or less as a unit, the *plate-and-angle separator* in Fig. 142*i* being more effective in this respect than the *pipe separator* in Fig. 142*j*. If the beams are not too far apart, two overlapping angles, with legs riveted together, can be used as an *angle separator.* Separators spaced 5 or 6 ft. apart are usually required when beams are used in pairs.

Lintels. The sections shown in Fig. 142*k* to *n* are lintels arranged to carry brick or stone masonry over openings and can be largely concealed. The single angle shown in Fig. 142*n* carries the outer layer of masonry, while the remainder of the wall may be carried by a *relieving arch* or else another angle may be used.

Plate Girders. A built-up plate girder is illustrated in Fig. 142*o*.[8] The section consists of four flange angles, a web plate, and cover plates, as shown in Fig. 142*f*. The web plate is usually made quite thin, a ratio of unsupported depth to thickness of 170 being permitted if *web stiffeners* are provided, as shown in the figure, to keep the web plate

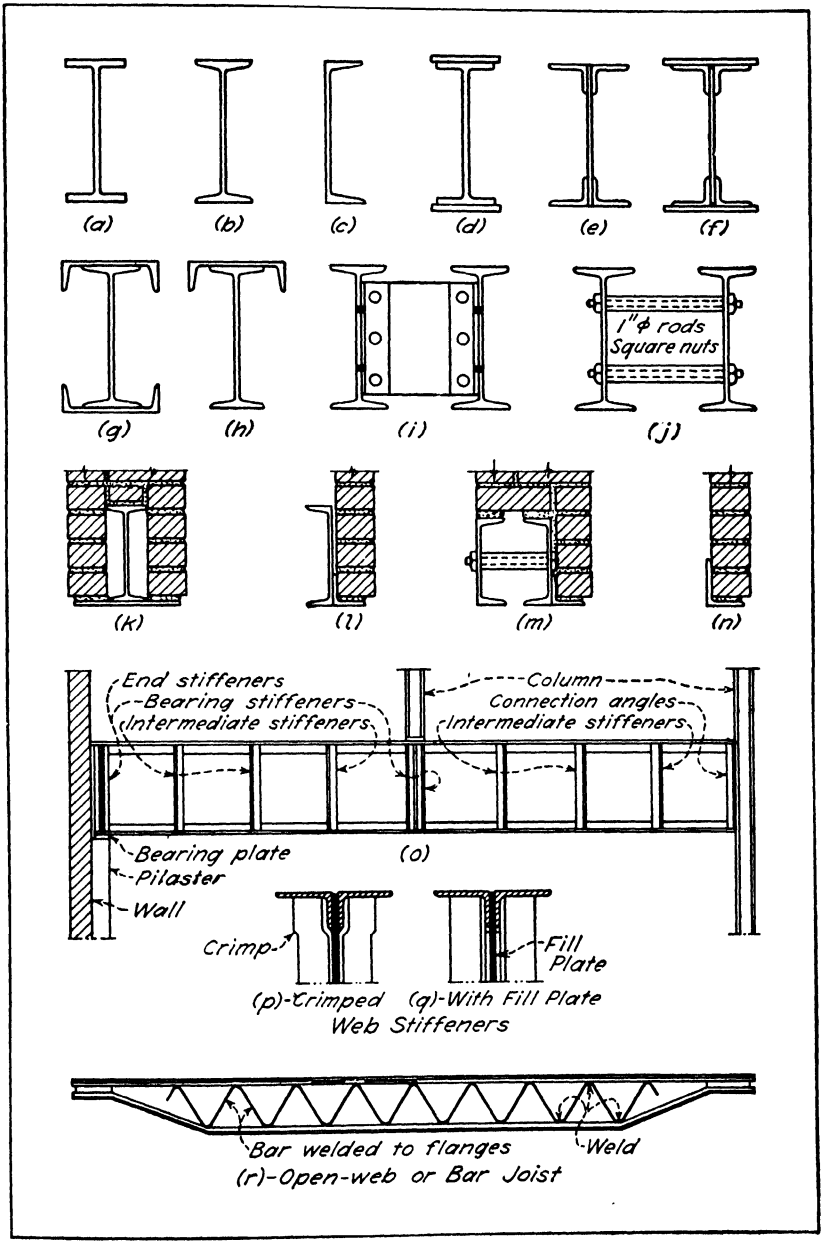


FIG. 142. Steel Beams

from buckling. Since these stiffeners must project over the flanges, it is necessary to bend or *crimp* them around the vertical legs of the flange angles in order to place them against the web, as shown in Fig. 142*p*; or *fill plates,* equal in thickness to the flange angles, may be placed between the stiffeners and the web plate, as shown in Fig. 142*q*. If the unsupported depth of the web does not exceed 70 times its thickness, *intermediate stiffeners* are not required but *end stiffeners* are always required. Stiffeners are also required at all points where concentrated loads are supported. The spacing of stiffeners is determined by the shearing stresses. It is often required that the thickness of web plates be at least $\frac{1}{4}$ in.

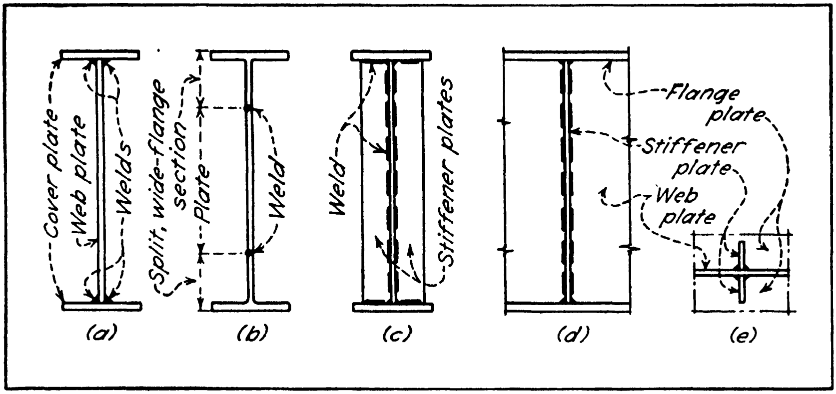


FIG. 143. Welded Plate Girders

A girder may be built up of two flange plates and a web plate welded together as shown in Fig. 143*a*, or of a wide-flange section, split along the center of the web and separated to receive a narrow plate which increases the depth as shown in Fig. 143*b*, the three parts being welded together. Stiffeners are provided by welding plates between the flanges and normal to the web (Fig. 143*c* to *e*). Welded girders are lighter than riveted girders for the same carrying capacity.

Joists. In cases where the loads are rather large and joists are widely spaced, I beams may prove economical, but special lightweight sections are available for light loads and closely spaced joists. One type of lightweight joist is the *junior beam* which is a rolled section of the same form as the standard I beam, but much lighter because the metal is rolled thinner. The sizes vary from a 6-in. depth weighing 4.4 lb. per ft. to the 12-in. depth weighing 11.8 lb. per ft. The web thickness of the smaller section is less than $\frac{1}{8}$ in., and of the larger

section about $\frac{3}{16}$ in. Other sections lighter than the American standard sections are available.

Another form of joist for light loads is the *open-web* or *trussed joist*, one type of which is illustrated diagrammatically in Fig. 142*r*. The flanges of joists of this type are made up either of two light angles or a tee, with web members consisting of flat bars welded to the flanges, or of a continuous round bar bent back and forth to form the diagonals and welded to the flanges. Some types are called *bar joists* because they are made up largely of bars.

ARTICLE 46. STEEL TRUSSES

The various types of steel trusses have been described in Art. 34. The members of steel roof trusses are usually composed of one or two angles. Minor members carrying small stresses may be made of a single angle as small as $2\frac{1}{2}$ by 2 by $\frac{1}{4}$ in. in some cases. Members composed of two small angles placed back to back, as shown in Fig. 144*a*, with sufficient distance between them to permit connection plates to enter, are preferred to members composed of one larger angle.

The details of a Fink roof truss are shown in Fig. 144*b*. The members are connected together at the joints by *connection* or *gusset plates* to which the members are riveted, as shown in the figure. These plates vary in thickness from $\frac{1}{4}$ in. to $\frac{5}{8}$ in. and are made large enough to provide for the number of rivets required by the stresses in the members. The rivets are usually $\frac{5}{8}$ in. or $\frac{3}{4}$ in. in diameter.

If the top chord of a roof truss is subjected to bending stresses by loads which are not applied at the joints it may be composed of two angles and a plate, as shown in Fig. 145*a*. Similarly a bottom chord which is subjected to bending stresses may be made of two angles and a plate, as shown in Fig. 145*b*. It is sometimes desirable or necessary to use two channels placed back to back, as shown in Fig. 145*c*, for the bottom chord.

All truss members consisting of two angles or two channels placed back to back, as shown in Fig. 144*b*, should be provided with *stitch rivets* at intermediate points between the connection plates. The distance between the backs of the angles or channels is maintained by washers through which the rivets pass. Stitch rivets are provided to make the individual parts act together more nearly as a unit.

Timber or steel purlins are fastened to the top chords of steel roof trusses by means of short lengths of steel angles, called *clip angles*, as shown in Figs. 144*b* and 145*d*.

Steel trusses are frequently used as a part of the interior framing of tall buildings to span auditoriums, lobbies, banquet halls, dance halls,

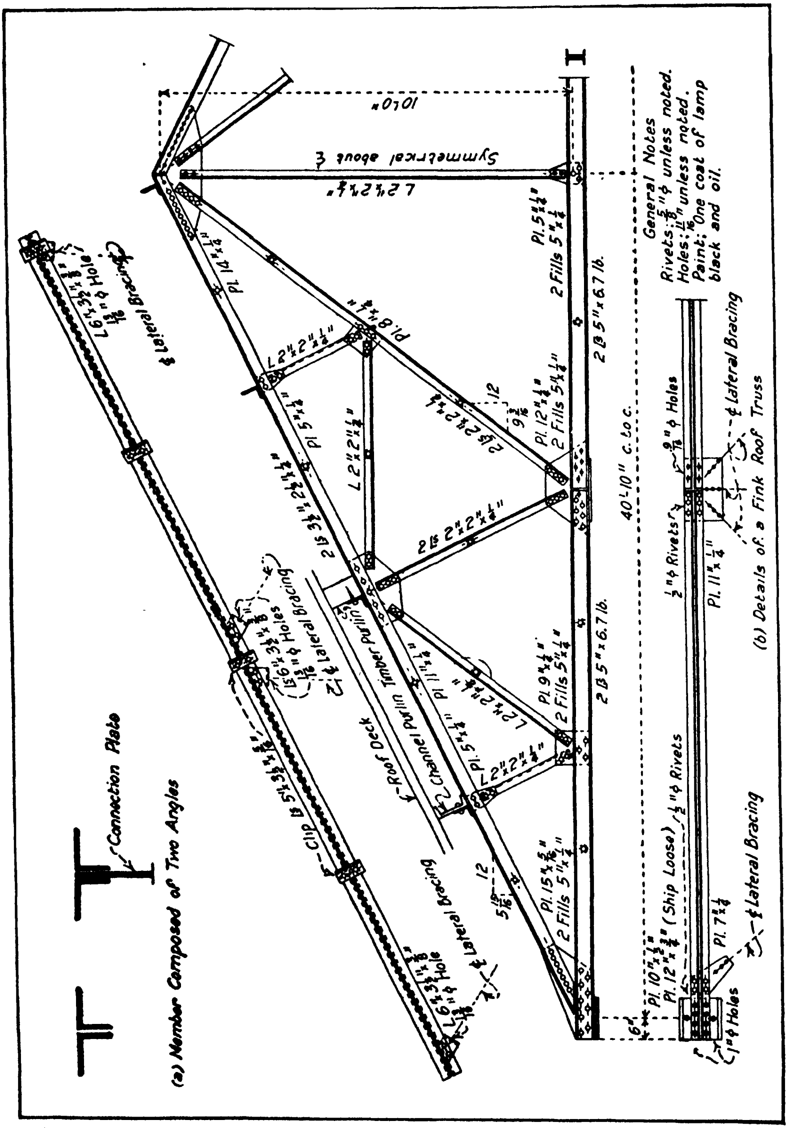


FIG. 144. Fink Steel Roof Truss

and other rooms requiring large floor areas free from columns. Such floors are preferably located at the top or near the top of the building in consideration of the economy in the structural framing, but other considerations may make it necessary to place these large floor areas in any part of a building. Very commonly they will be on the first floor with fifteen or twenty stories above, as shown in Fig. 146*a*. The depth of the truss may occupy one or more stories. It may not be possible to use one of the common types of truss because of doors or

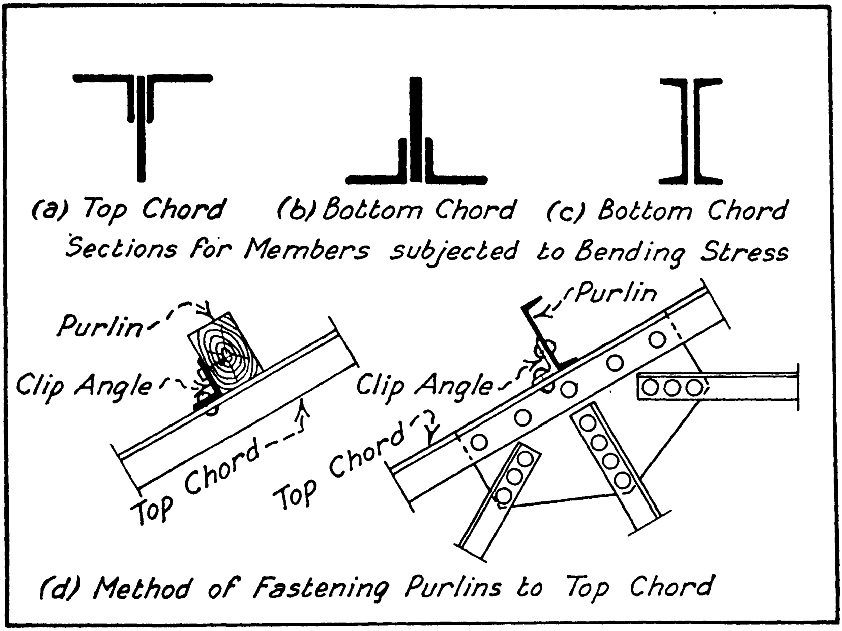


FIG. 145. Simple Steel Roof Truss Details

hallways, for the floor or floors immediately above may have to pass through the truss and will determine its form. Such trusses have to be of very heavy construction. Typical cross-sections of truss members are given in Fig. 146*b*.

Another common use for steel trusses is the support of the balconies of theaters. Columns are of course objectionable on account of their obstruction of the vision; so they are eliminated whenever possible. A common form of construction consists of cantilever trusses overhanging a transverse supporting truss or girder, as shown in Fig. 146*c*.

Long-span or heavily loaded trusses may be composed of members such as illustrated in Figs. 146*b* and 147*b*.

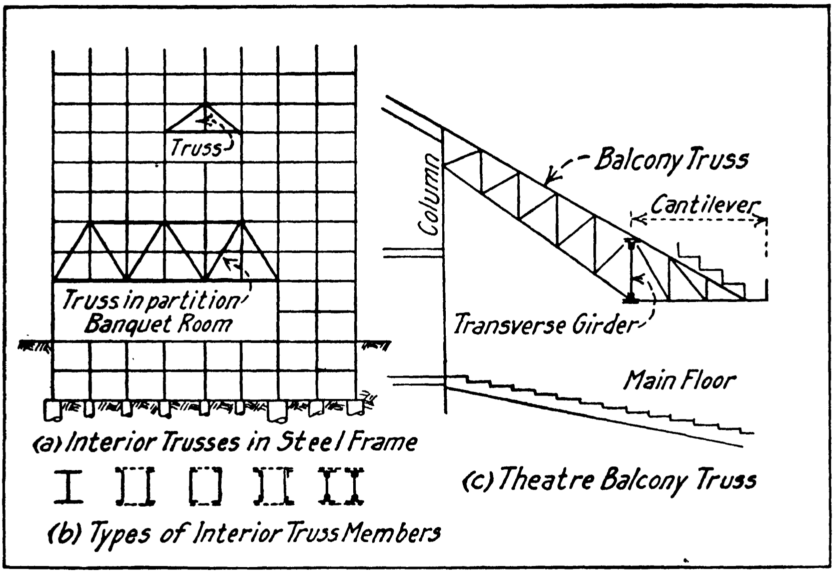


FIG. 146. Trusses Located in Partitions and Balcony Truss

ARTICLE 47. STEEL ARCHES AND RIGID FRAMES

Arches. Structural-steel arches are more commonly used than any other type of arch for long spans which are too great for the economical use of trusses. They are used to support the roofs over drill halls, gymnasiums, hangars, etc. They are usually of the framed type, but may be ribbed. The most common form of steel arch in building construction is the framed arch with three hinges, as shown in Fig. 147*a*, although the two-hinged arch shown in Fig. 147*b* is used.

The method used in fastening the various members of a framed arch at the joints is the same as that described for roof trusses. The members are riveted to connection plates.

The chord members may be made of H sections or two channels fastened together with lacing bars, as shown in Fig. 147*c*; or with a cover plate on top and lacing bars at the bottom, as shown in Fig. 147*d*; or of four angles and a web plate, as shown in Fig. 147*e*. The web members may consist of H sections, of four angles laced or with a web plate, or of two channels laced as shown in Fig. 147*f*; but laced members are rarely used. Two angles placed back to back as described for roof trusses are used extensively in arch construction for chord and web members.

The foundations may be designed to take the horizontal thrusts of the arch, but ties passing under the floor and joining the two end joints,

as shown in Figs. 147 to 149, are more commonly used. These ties may be rods, steel sections, or the floor itself may be used when properly designed to carry the thrust.

In the three-hinged arch illustrated in Fig. 148 most of the members are composed of two angles placed back to back with a sufficient

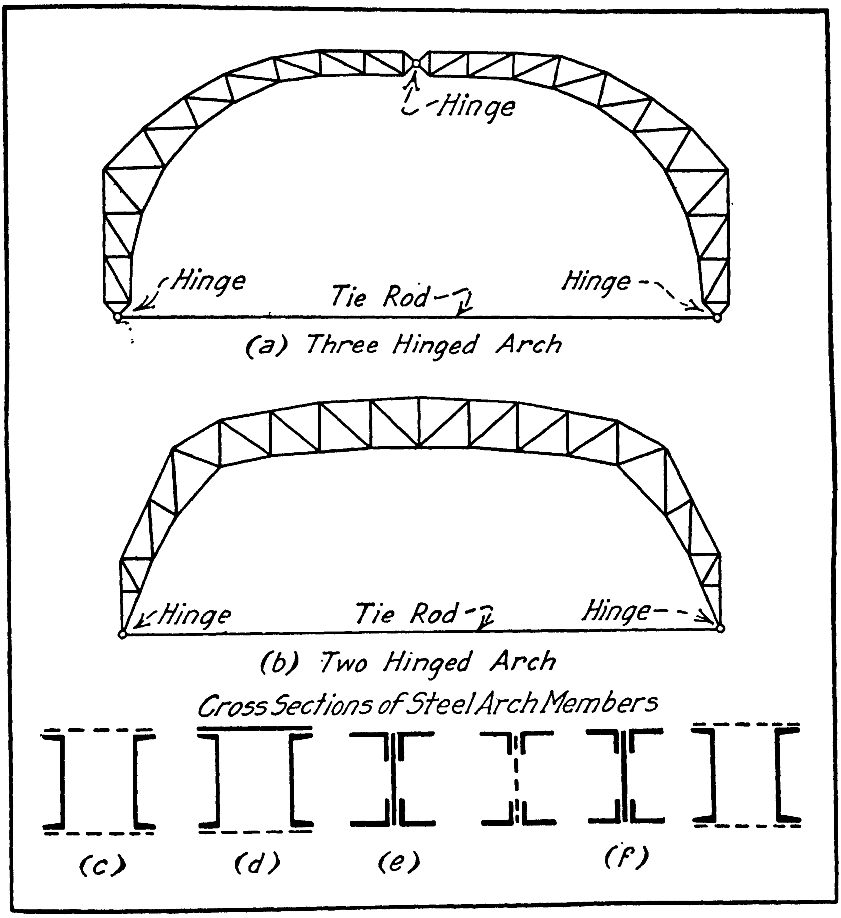


FIG. 147. Steel Arches

distance between them to permit the connection plates to enter. Near the ends the lower chord is reinforced with cover plates.

Balconies are often provided, as shown in Fig. 149.

Ribbed arches with spans exceeding 300 ft. can be constructed of sections of wide-flange beams welded together or joined end to end by

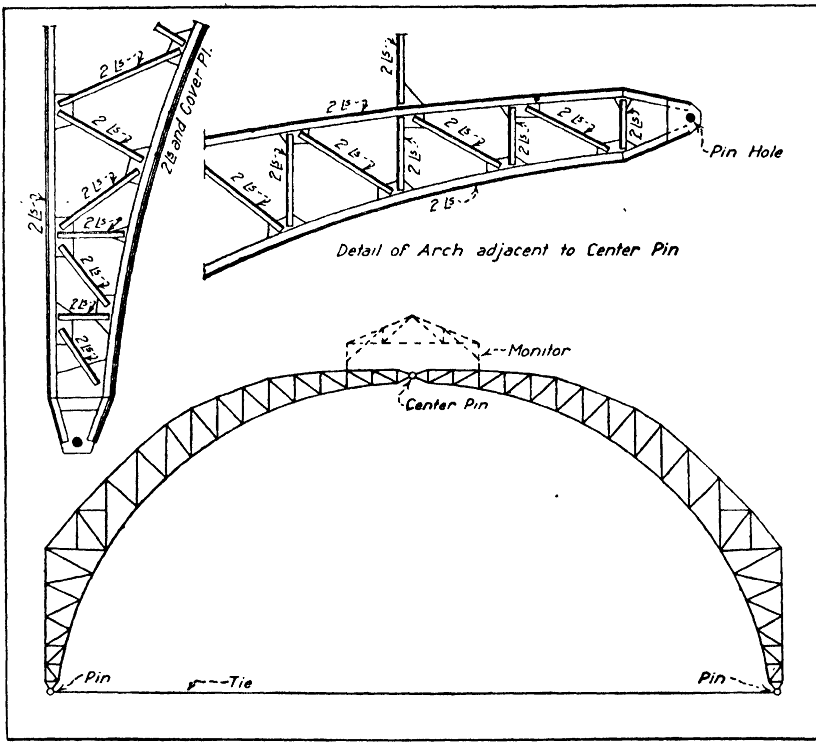


FIG. 148. Three-Hinged Steel Arch

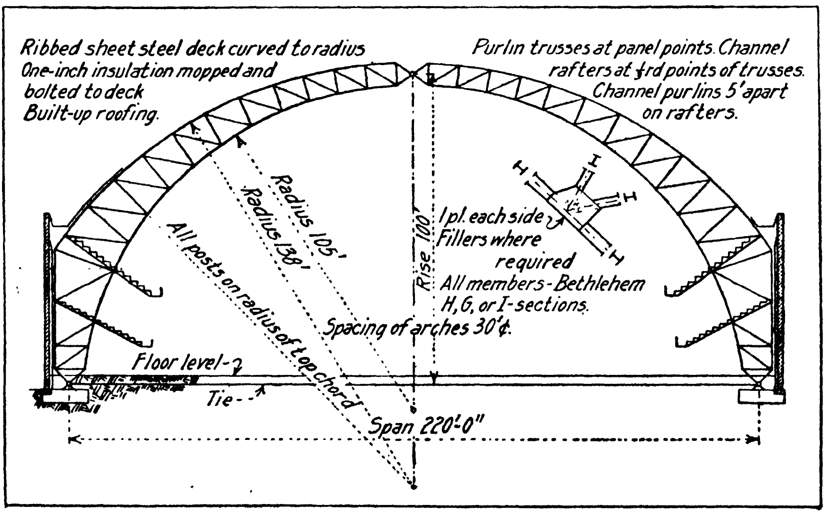


FIG. 149. Three-Hinged Steel Arch, University of Minnesota Field House

special connectors, one type of which is patented. One example, using these patented connectors, has a span of 255 ft., a rise of 64 ft., and is made up of 18 sections of 33-in. wide-flange beams. Arches of this type may be three-hinged, two-hinged, or fixed. The end thrusts of such arches may be provided for in various ways, including ties under

Photo by Civil Aeronautics Administration

FIG. 150. Hangar at Washington National Airport with Steel-Ribbed Arches

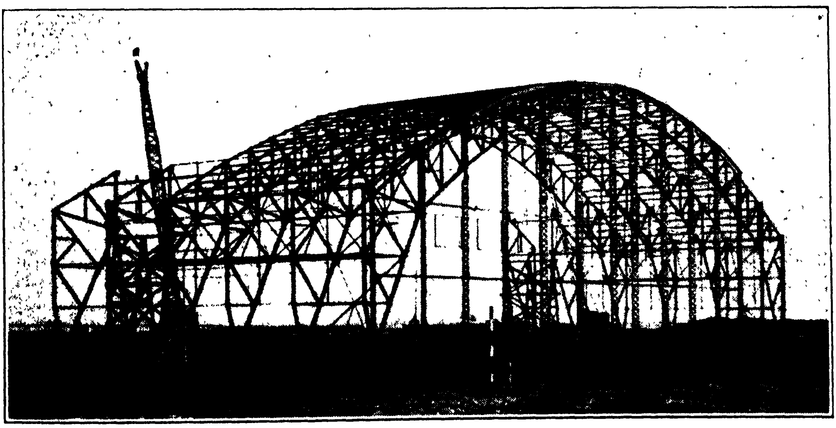


Photo by U. S. Army Air Corps

FIG. 151. Three-Hinged Steel-Framed Arches of Hangar at Chanute Field, Illinois

the floor. Arch ribs are also built up of plates and angles with sections as shown in Fig. 142*e* and *f*.

Rigid Frames. Steel rigid frames have come into extensive use during recent years for field houses, exhibition halls, armories, gym-

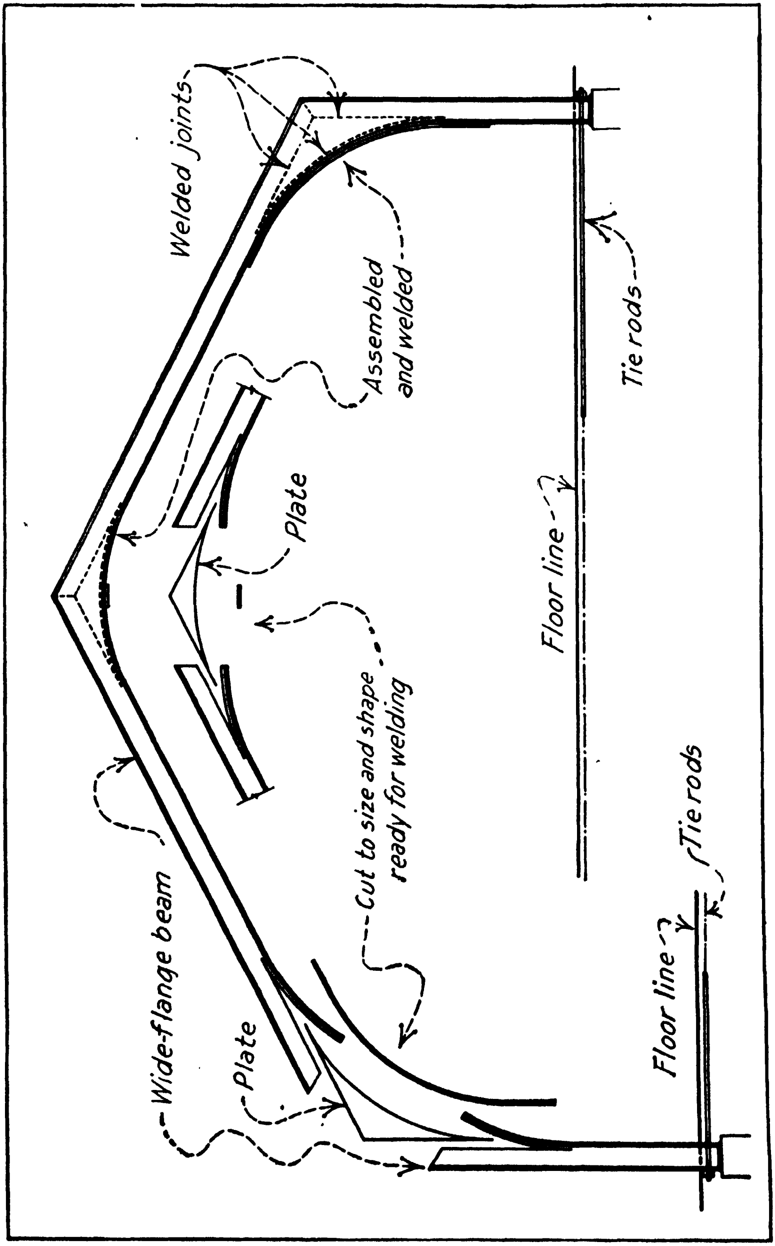


FIG. 152. Method of Fabricating Welded-Steel Rigid Frame

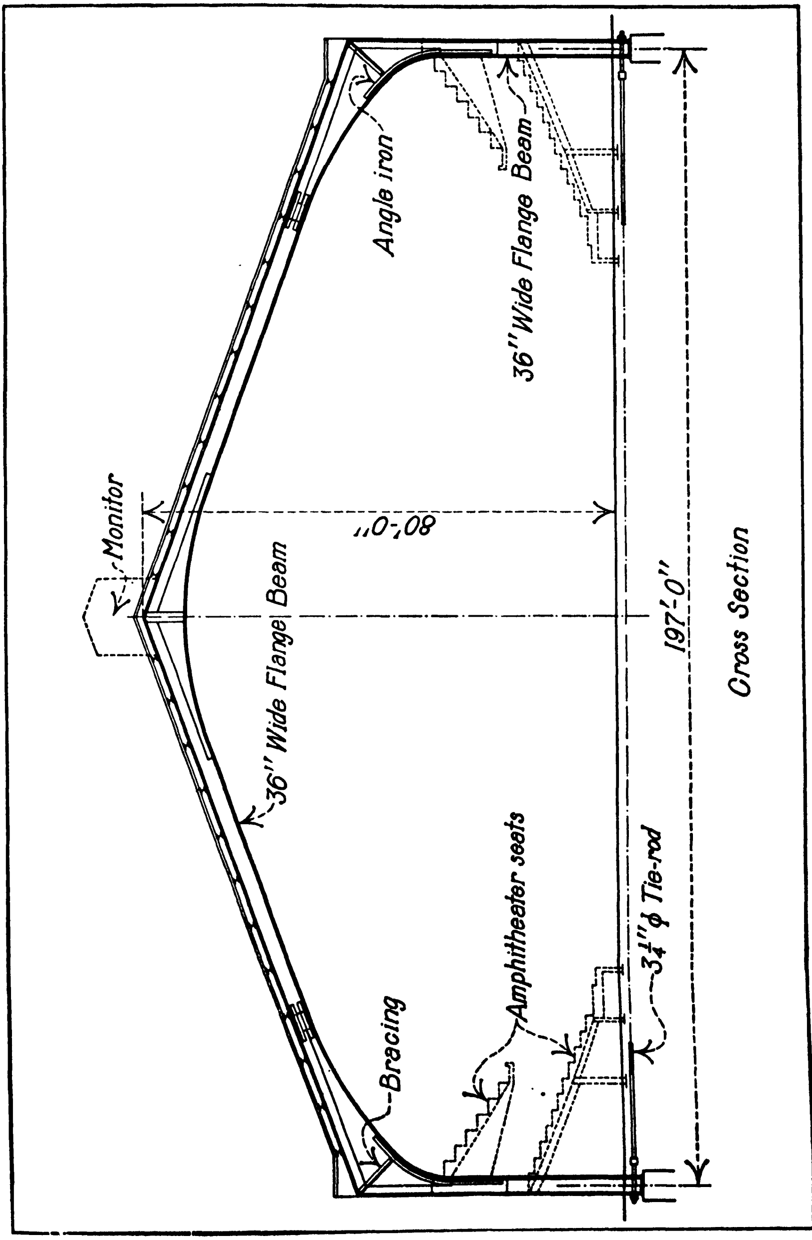
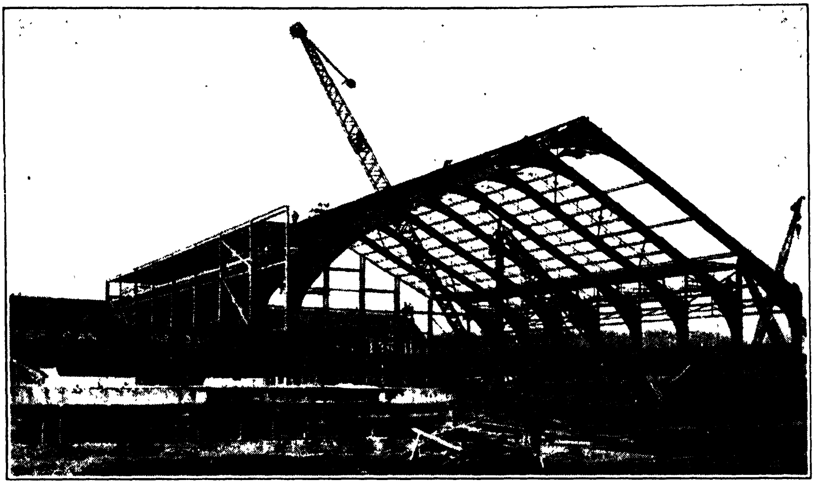


FIG. 153. Rigid Frame in Amphitheater at Chicago Stock Yards

nasiums, hangars, and other buildings requiring large unobstructed floor areas, good headroom, and attractive but unfinished ceilings. Spans exceeding 200 ft. have been constructed and considerably longer spans will doubtless be built in the future.



American Institute of Steel Construction

FIG. 154. Rigid Frames in Amphitheatre at Chicago Stock Yards

FIG. 155. Rigid Frames in Field House at University of Colorado

The type of construction is illustrated in Fig. 152. The columns and sloping members are made continuous to form a rib extending from support to support, with the outward thrust at the reaction carried by steel tie rods located in, or just under, the floor. The ribs are formed from four wide-flange sections cut to form, split by flame-cutting the ends just above the bottom flange, and bent as shown on the left side and at the top of the figure to deepen the rib at the eaves or *knees* and at the ridge or *crown*. The triangular openings thus formed are filled

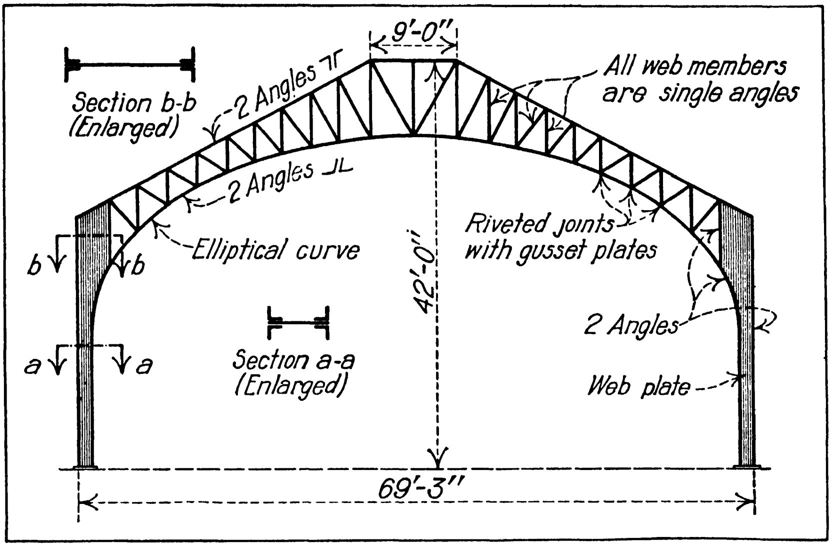


Fig. 156. Trussed Rigid Frame

with plates which are welded to the wide-flange sections, as shown on the right side and at the top of the figure, to form the continuous frame.

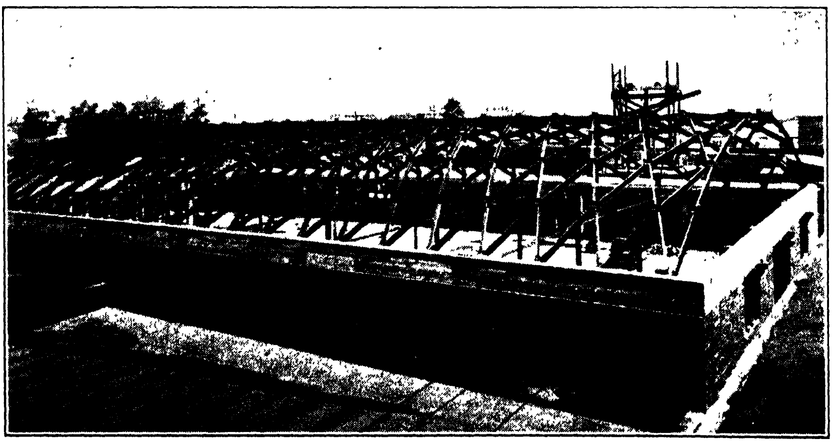
In the earlier frames, shown in Fig. 153, the triangular plates were riveted to split edges of the sections, one plate being placed on each side of the web. The welded construction has proved simpler and superior to the riveted construction.

Trussed bracing is provided at the eaves and at the ridge, as shown in Fig. 153. In frames with longer spans, the 36-in. wide-flange section has been used. The frames are commonly shipped and erected in four pieces with field splices at the crown and knees. This type of construction was developed by the American Bridge Company which designates it as *beam arch construction*. For photographs showing steel rigid-frame construction see Figs. 154 and 155.

The frame shown in Fig. 156 might be classed as a two-hinged arch but since there would be large bending stresses in the columns it is

Lincoln Electric Co.

FIG. 157. Saw-Tooth Roof with Welded-Steel Rigid Frames



Lamella Roof Syndicate

FIG. 158. Steel Lamella Roof

really a rigid frame. The column sections are built up of form angles and a plate, the chords of two angles back to back and the

web members of single angles. The bottom chord is bent to the curve shown in the figure. The frame was erected in four pieces with field joints or splices one panel away from the crown and near the knees.

Various other forms of roof construction make use of welded-steel rigid frames. A saw-tooth roof with welded rigid frames is shown in Fig. 157.

Lamella Roofs. Lamella Roofs, as described in Art. 41 and illustrated in Figs. 125 and 126, are constructed of steel members as well as of wood members. This type of construction is illustrated in Fig. 158. The arches may be tied, or buttressed supports may be provided to take the arch thrust.

ARTICLE 48. STRUCTURAL-STEEL FRAMING

General Methods. Structural-steel members are fastened together by means of rivets, bolts, or welding. In general, the parts assembled in the fabricating shop will be *shop-riveted,* but welding is also used for this purpose, particularly on light members. There has been considerable opposition to the use of rivets in tension, but experimental investigations have shown that rivets can be relied upon when used in tension and that there are no sound reasons for prohibiting their use in this manner.

Connections made at the building site during erection are called *field connections.* These are usually riveted or made with *unfinished bolts,* except in special cases where *turned bolts* are required, or else they may be welded. The conditions under which rivets and bolts are used are considered more fully in a subsequent paragraph. The use of welding in making field connections is increasing. The structural frames for buildings as tall as 20 stories have been completely welded. One of the advantages of welding is the freedom from the noise which accompanies field riveting. Such noise is particularly objectionable in the business districts where tall buildings are usually built.

Shearing. Structural-steel plates and bars are usually cut to size by shears. These are of various forms to suit the shapes of the sections to be cut, such as beam shears, angle shears, and plate shears.[2]

Flame-Cutting. Another method used for cutting structural steel is called *flame-cutting, gas-cutting,* or *oxygen-cutting.* This is done with an oxyacetylene cutting torch. The cutting can be done with portable hand-cutting equipment or with the more elaborate machine-cutting equipment. The actual cutting is done by directing a stream of oxygen against a surface heated to about 1600 deg. fahr. The steel

is oxidized or burns out along the kerf where the cut is made. The steel is heated with a flame created by burning a mixture of oxygen and acetylene. Heating jets which are located in the tip of the cutting torch surround a single cutting jet. Flame-cutting can be used on steel of any thickness which might be encountered. Cuts of any form can be made rapidly and accurately. Plates $\frac{1}{4}$ in. thick can be cut at the rate of 20 in. per min., and plates 10 in. thick at the rate of $3\frac{1}{2}$ in. per min. Flame-cutting hardens the metal to a depth of about $\frac{1}{32}$ in. on each side of the kerf for steel $\frac{1}{2}$ in. thick, and about $\frac{1}{8}$ in. for steel 6 in. thick.[3]

Types of Rivets. Rivets are used in fastening the various parts of a structural-steel member together and in connecting members together. The first operation is usually performed in the shop and is called *fabricating,* and the last operation is usually performed at the site as the building is being *erected.* The rivets used in building construction

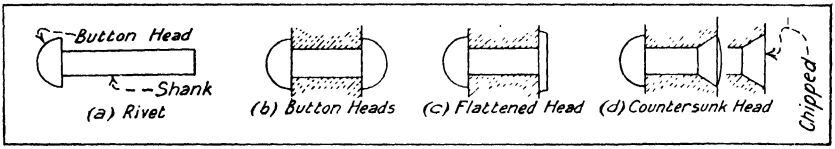


FIG. 159. Rivets and Rivet Heads

are made of soft steel. They usually consist of a hemispherical button-shaped head and a cylindrical shank, as shown in Fig. 159*a*. In driving, a rivet is heated red hot and placed in a hole through the members which it is to assist in connecting. The projecting end is then upset to form a head, using a pneumatic or hydraulic riveter, there being a depression in the head of the riveter to give the rivet head the proper shape. The other end of the rivet is held in place by a *dolly,* or similar contrivance, while the rivet is being driven.

As rivets cool, they contract and tighten their grip. This action sets up considerable frictional resistance between the pieces connected and augments the shearing resistance of the rivets but is not considered in determining the number of rivets required.

Rivets are driven in the field or on the job by portable pneumatic riveters called *guns.* Rivet heads may be of various shapes to suit special conditions. The *button head* shown in Fig. 159*b* is the shape usually used. To provide clearance, the *flattened head* shown in Fig. 159*c* or the *countersunk head* shown in Fig. 159*d* may be used. Countersunk heads which have been *chipped* flush with the surface must be used on bearing plates and column bases so that they will not interfere with the bearing.

In structural steel details the heads of shop-driven rivets are shown in plan by circles the size of the head, but field rivets are indicated in plan by circles the size of the holes. For field rivets, the circles are filled in black.

The line passing through the centers of a row of rivets is called a *gage line.* The spacing of rivets, center to center, is called the *pitch.* The distance from the center of a rivet to the nearest edge is called the *edge distance.* The length of a rivet, as determined by the total thickness of the material it penetrates, is called the *grip.*

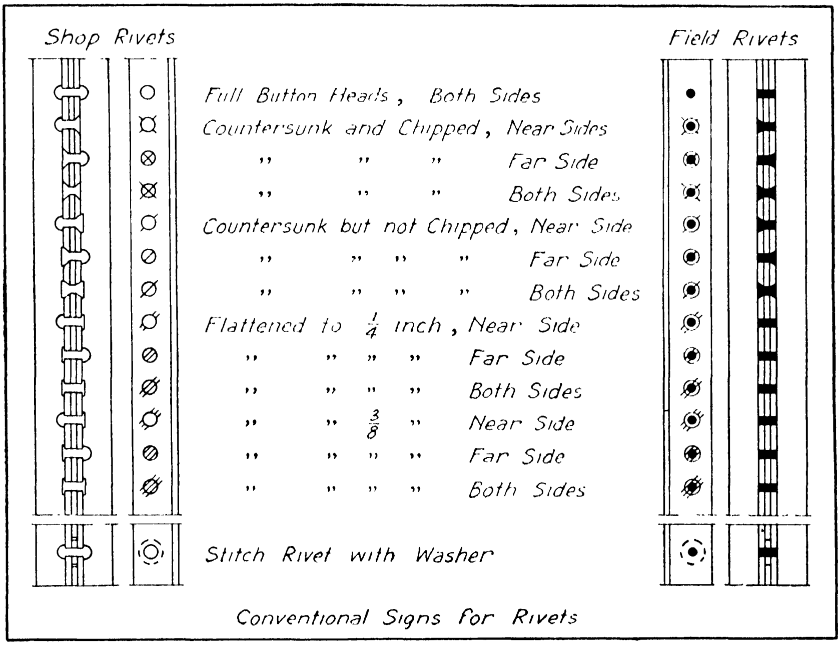


FIG. 160. Conventional Signs for Rivets

The conventions used on structural drawings to represent rivets of various types are shown in Fig. 160.

Riveting and Bolting Requirements. The *size* of rivet and bolt most commonly used on ordinary work is that with a diameter of $\frac{3}{4}$ in. before driving, but $\frac{7}{8}$-in. rivets are extensively used. On light work $\frac{1}{2}$-in. or $\frac{5}{8}$-in. rivets may be used, and on very heavy work the rivets are commonly 1 in. or $1\frac{1}{8}$ in. in diameter. The following requirements are taken from the Specifications for the Design, Fabrication, and Erection of Structural Steel for Buildings of the American Institute of Steel Construction, 1939.[1]

Use of Rivets. Rivets shall be used for the following connections:

1. Column splices in all tier structures 200 ft. or more in height.
2. Column splices in tier structures 100 ft. to 200 ft. in height if the least horizontal dimension is less than 40 per cent of the height.
3. Column splices in tier structures less than 100 ft. in height if the least horizontal dimension is less than 25 per cent of the height.
4. Connections of all beams and girders to columns, and any other beams and girders on which the bracing of columns is dependent, in structures over 125 ft. in height.
5. Roof-truss splices and connection to columns.
6. Column splices, column bracing, and crane supports in all structures carrying cranes of over 5-ton capacity.
7. Connections for supports of running machinery or of other live loads which produce impact or reversal.
8. All other connections stipulated on the design plans.

Use of Bolts. All field connections may be made with unfinished bolts, except as provided above.

Turned bolts in reamed or drilled holes may be used in shop and field work where it is impossible to drive satisfactory rivets. The finished shank shall be long enough to provide full bearing, and washers shall be used under the nuts to give full grip when the nuts are turned tight.

Minimum Pitch. The preferable minimum distance between centers of rivet holes shall be not less than $4\frac{1}{2}$ in. for $1\frac{1}{4}$-in. rivets; 4 in. for $1\frac{1}{8}$-in. rivets; $3\frac{1}{2}$ in. for 1-in. rivets; 3 in. for $\frac{7}{8}$-in. rivets; $2\frac{1}{2}$ in. for $\frac{3}{4}$-in. rivets; 2 in. for $\frac{5}{8}$-in. rivets; and $1\frac{3}{4}$ in. for $\frac{1}{2}$-in. rivets; but in no case shall it be less than 3 times the diameter of the rivet.

Maximum Pitch. The maximum pitch in the line of stress of compression members composed of plates and shapes shall not exceed 16 times the thickness of the thinnest outside plate or shape, nor 20 times the thickness of the thinnest enclosed plate or shape with a maximum of 12 in.; and at right angles to the direction of stress the distance between lines of rivets shall not exceed 30 times the thickness of the thinnest plate or shape. For angles in built sections with two gage lines, with rivets staggered, the maximum pitch in the line of stress in each gage line shall not exceed 24 times the thickness of the thinnest plate with a maximum of 18 in.

The pitch of rivets at the ends of built compression members shall not exceed four diameters of the rivets for a length equal to $1\frac{1}{2}$ times the maximum width of the member.

In tension members composed of two angles, a pitch of 3 ft. 6 in. will be allowed, and in compression members, 2 ft. 0 in., but the ratio

of the length between rivets to the radius of gyration for each angle shall not be more than three-quarters that for the whole member. This is called the *slenderness ratio.* The intermediate rivets are called *stitch rivets.*

Edge Distance. The minimum distance from the center of any punched rivet hole to any edge shall be as follows:

MINIMUM EDGE DISTANCE

Rivet Diameter in Inches	Minimum Edge, Distance in Inches for Punched Holes		
	In sheared edge	In rolled edge of plates and sections with parallel flanges	In rolled edge of plates and sections with sloping flanges
$\frac{1}{2}$	1	$\frac{7}{8}$	$\frac{3}{4}$
$\frac{5}{8}$	$1\frac{1}{8}$	1	$\frac{7}{8}$
$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{1}{8}$	1
$\frac{7}{8}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{8}$
1	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$
$1\frac{1}{8}$	2	$1\frac{3}{4}$	$1\frac{1}{2}$
$1\frac{1}{4}$	$2\frac{1}{4}$	2	$1\frac{3}{4}$

The maximum distance from the center of any rivet to the near edge shall be 12 times the thickness of the plate, but shall not exceed 6 in.

Holes. Holes for rivets or unfinished bolts shall be $\frac{1}{16}$ in. larger than the nominal diameter of the rivet or bolt. If the thickness of the material is not greater than the nominal diameter of the rivet or bolt plus $\frac{1}{8}$ in., the holes may be punched. If the thickness of the material is greater than the nominal diameter of the rivet or bolt plus $\frac{1}{8}$ in., the holes shall be either *drilled* from the solid or *subpunched* and *reamed.* The die for all subpunched holes and the drill for all subdrilled holes shall be $\frac{1}{16}$ in. smaller than the nominal diameter of the rivet or bolt.

Holes for turned bolts shall be $\frac{1}{50}$ in. larger than the external diameter of the bolt. If bolts are to be inserted in the shop, the holes may be either drilled from the solid or subpunched and reamed. If the bolts are to be inserted in the field, the holes shall be subpunched in the shop and reamed in the field. All drilling or reaming for turned bolts shall be done after the parts to be connected are assembled.

Drifting to enlarge *unfair holes* shall not be permitted. Holes that must be enlarged to admit rivets shall be reamed. Poor matching of holes shall be cause for rejection. *Unfair holes* are holes which do not match. *Drifting* consists of driving a tapered bar called a *drift pin*

into the holes to make them match. Drifting is permissible when it is done to draw members into position without enlarging the holes.

Riveting. All rivets are to be power-driven hot. Rivets driven by pneumatically or electrically operated hammers are considered *power-driven.* Standard rivets shall be approximately hemispherical in shape, of uniform size throughout the work for the same-sized rivet, neatly finished, and concentric with the holes. Rivets, after driving, shall be tight, completely filling the holes, and with heads in full contact with the surface. Rivets shall be heated uniformly to a temperature not exceeding 1950 deg. fahr.; they shall not be driven after their temperature is below 1000 deg. fahr.

Loose, burned, or otherwise defective rivets shall be replaced.

The method of riveting together the various parts of the column section shown in Fig. 141*d* is illustrated in Fig. 141*p*. The use of lacing bars to fasten the parts of a column together is illustrated in Fig. 141*q*. These figures show only a part of the length of a column. Lacing bars are rarely used in building construction.

Welding Processes. There are many processes used in welding pieces of metal together. Those used in structural welding are divided into two main groups, i.e., *pressure processes* in which the weld is completed by applying pressure after the pieces to be welded have been placed in contact where the weld is to be formed and have been heated to the required temperature; and the *non-pressure* or *fusion process* which requires no pressure to complete the weld.

Non-pressure or fusion processes used in structural welding are divided into arc welding and gas welding according to the source of heat, as follows:

In *arc welding,* the heat is provided by an electric arc formed between the work to be welded and an electrode held in the operator's hand with a suitable holder or in an automatic machine. The electrode may be a metallic rod, as in *metal arc welding,* or a carbon rod, as in *carbon arc welding.*

In *gas welding,* the heat is provided by a gas flame produced by burning a mixture of oxygen and a suitable combustible gas. The flame is formed at the tip of a *blowpipe* or *torch* which is held in the operator's hand or in an automatic machine. The gas used in structural welding is acetylene which gives this process the name of the *oxyacetylene process.*

In both the arc and gas processes, the pieces to be welded are placed in contact and the edges are melted so that metal from the two pieces flows together and, when cooled, the pieces are joined by the weld. In order to make a satisfactory joint, additional metal must be supplied.

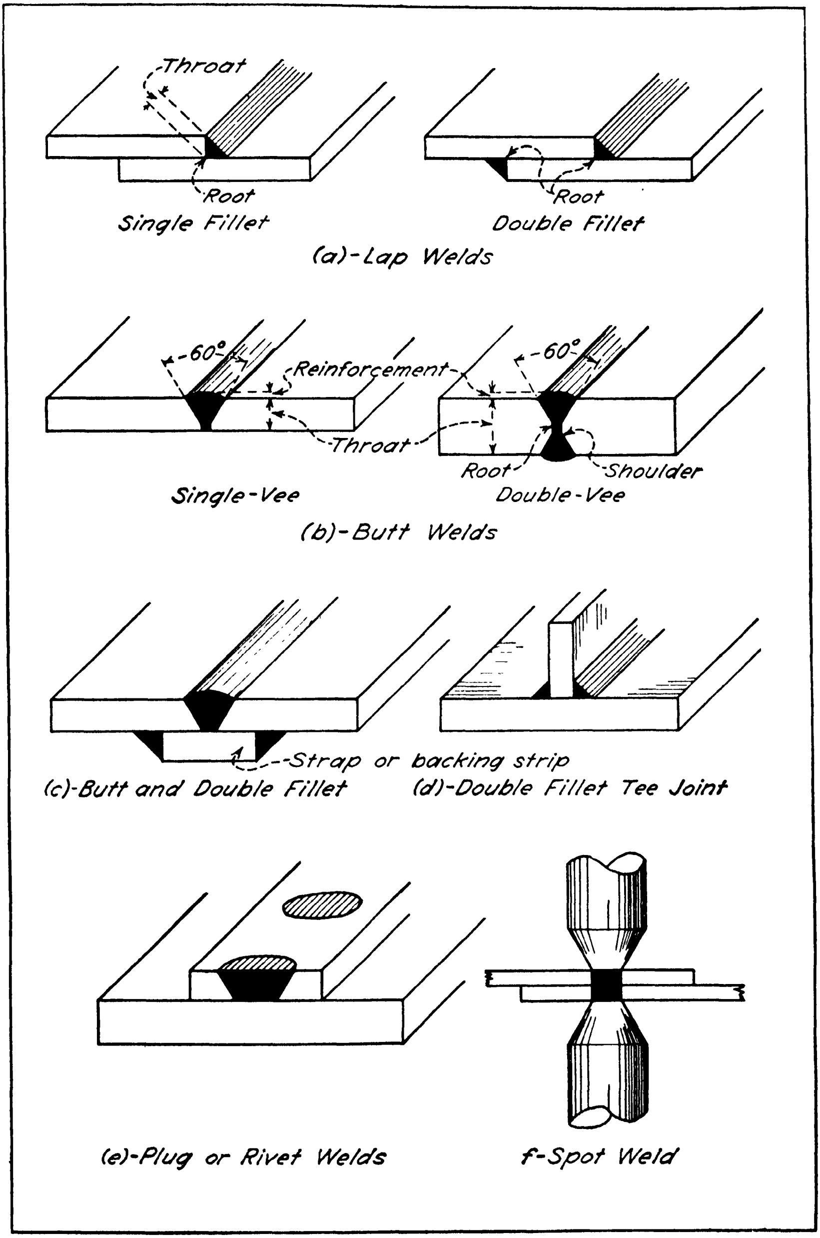


FIG. 161. Types of Welded Joints

This is provided by the metallic rod used as the electrode in the metal arc process, but in the carbon arc and in the gas processes a metal rod called a *filler* or *welding rod* is used. The end of this rod is melted off into the joint as the joint is being formed.

The only pressure-welding process used in structural work is the *spot-welding process.* In this process, a small area or spot on the surfaces to be joined is heated by placing electrodes against the outer surfaces of the pieces and passing an electric current through the pieces and across the contact surface. The heat required to raise the temperature of the pieces to a welding temperature at the spot where the weld is to be made is generated by the resistance offered by the metal between the electrodes to the flow of electric current. This is, therefore, a *resistance process.* The weld is consummated by exerting pressure across the spot so this is a *pressure process.* If spot welds are formed progressively in a continuous overlapping row the process is known as *seam welding.* Disk electrodes are used to apply the pressure.

Types of Welded Joints. Various types of welded joints used in structural work, with the names applied to the various parts of welds, are illustrated in Fig. 161. The types of welds illustrated are the *single* and *double-fillet lap weld* in Fig. 161*a*, the *single* and *double-vee butt weld* in Fig. 161*b*, the *butt weld* with double-fillet welded backing strip in Fig. 161*c*, the *double-fillet T weld* in Fig. 161*d*, and the *plug* or *rivet weld* in Fig. 161*e* — all of which are fusion welds — and the *spot weld* in Fig. 161*f*, which is a resistance-pressure weld. The electrodes are shown in this figure.

Typical welded connections for beams, girders, and columns are illustrated in Fig. 162 together with the standard welding symbols.

The use of flame-cutting and welding in fabricating a steel rigid frame is illustrated in Fig. 152 and described in Art. 47.

Riveted Lap and Butt Joints. Joints provided by riveting plates or parts of members which lap over each other, as shown in Fig. 163*a*, are called *lap joints.* Those formed by butting the ends of two parts together and fastening them together by rivets passing through a splice plate or connection plate, as shown in Fig. 163*b*, are called *butt joints.*

Column Splices. Steel column sections are usually made constant for two-story heights. Because of the change in the load on a column at each floor, it would be possible to save column material by reducing the column section in each story. This practice would be undesirable because the cost of the splices and the increase in erection costs would probably offset any saving in column section. In order that they will not interfere with the beam and girder connections, the splices are commonly made about 2 ft. above the floor line.

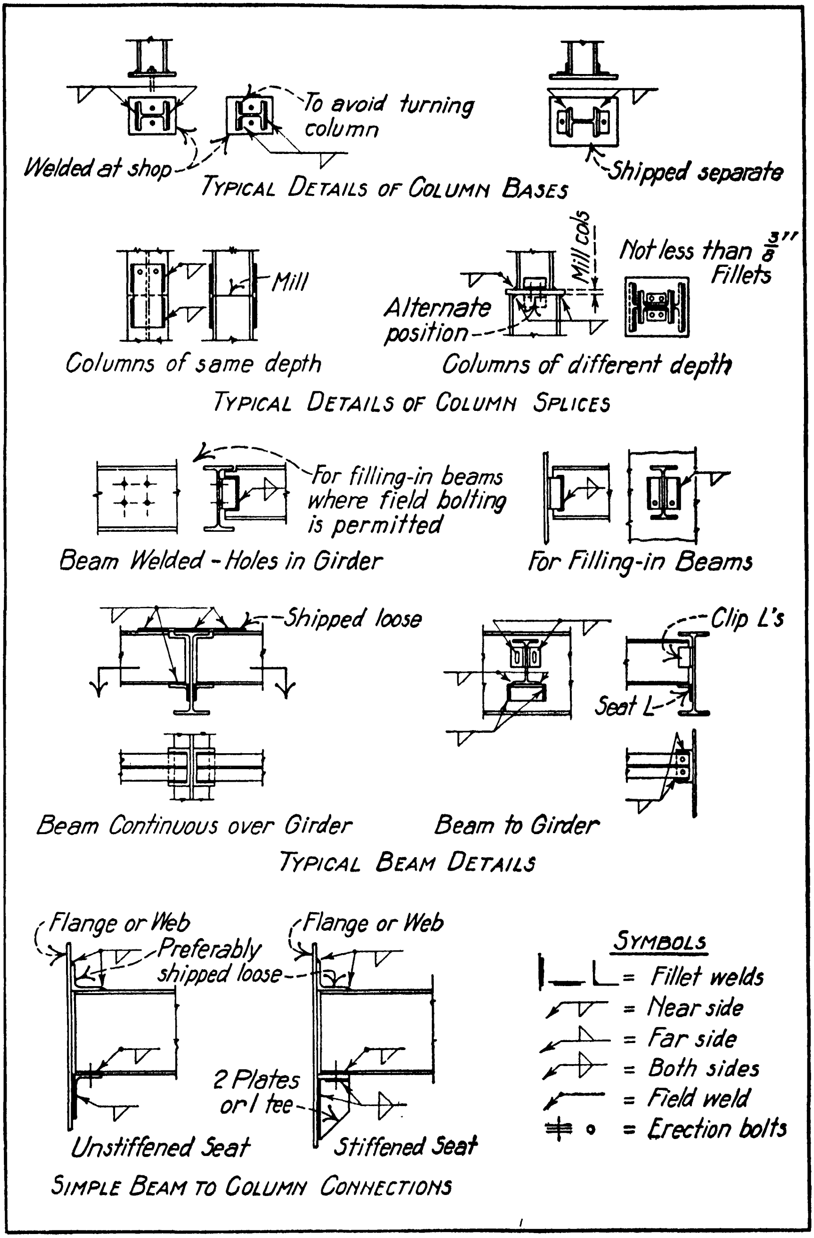


FIG. 162. Typical Welded Connections

The abutting ends of the columns at the splice are accurately *milled* so that the compressive stresses can be transferred directly from the upper column to the lower column by bearing. Splice plates are riveted to the flat sides of the columns and extend a short distance above and

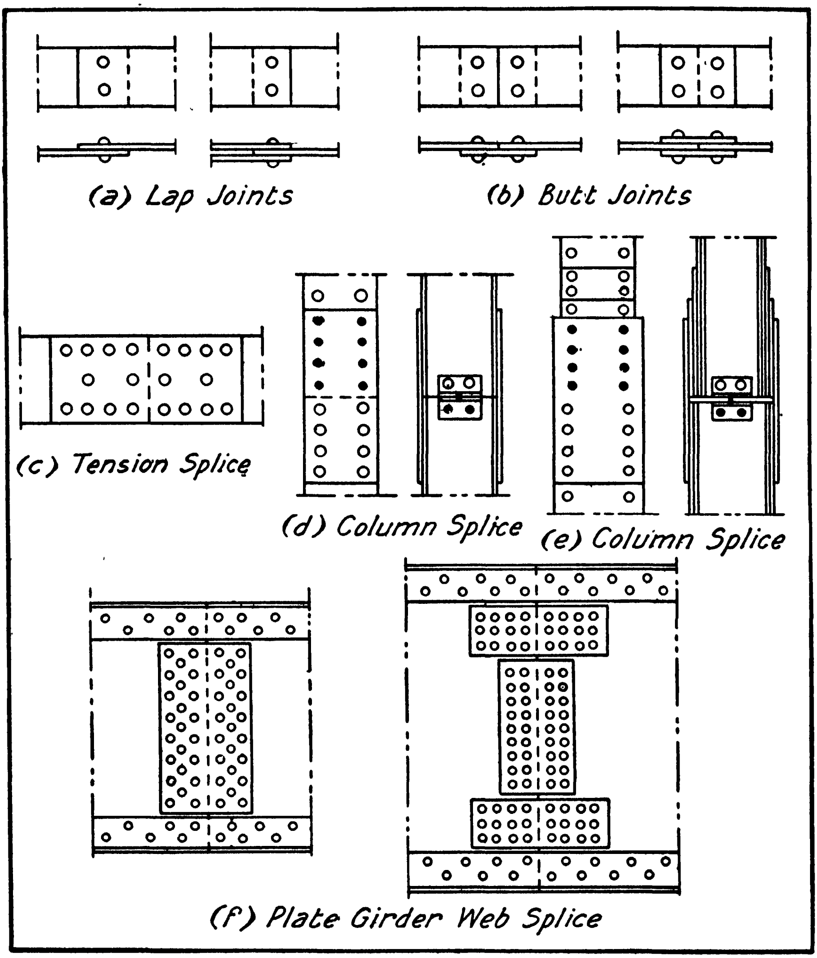


FIG. 163. Riveted Splices in Steel Members

below the abutting ends. The functions of these plates are to hold the two sections in line, to resist bending stresses due to wind and other causes, and to provide lateral rigidity. They are not relied upon to

transfer any of the direct load from one section to the other, with the possible exception of columns carrying very light loads.

If the two sections are of the same width, the splice is simple, as shown in Fig. 163*d*. If the widths are not the same, the difference in width is taken up by the *fill plates*, as shown in Fig. 163*e*. If the difference in width is so great that the flanges of the upper columns do not bear on those of the lower column, a horizontal bearing plate is inserted between the abutting ends as shown in the figure.

Splices in Plate-Girder Webs. The size of plates available for webs of plate girders is limited; so it is often necessary to splice these web plates. Two forms of *web splices* are shown in Fig. 163*f*.

End Connections of Bars and Rods. Bars and rods are used chiefly for lateral bracing and for ties and hangers. Their use is decreasing because rigid members such as angles are being substituted wherever possible.

The ends of rectangular bars are provided with eyes, as shown in Fig. 164*a*, and the bars are called *eye bars*. This type of member is only used with pin joints, as described later, and is therefore not used to any extent in building construction where the joints are usually riveted or bolted.

The ends of round and square bars may be provided with loops as shown in Fig. 164*b*. Such bars are called *loop bars* and are used only with pin joints, as described later, and therefore have little use in building construction. The loops are always square in cross-section.

The ends of round or square bars may be threaded to receive nuts to form an end connection. Several connections making use of nuts on *threaded ends* are shown in Fig. 164*c*. When long bars are used, it is usually economical to enlarge the end of the bar so that the area of the section at the root of the threads is somewhat greater than the area in the body of the bar. A smaller bar can then be used, for the threads do not reduce the section area. These enlarged ends are called *upset ends* and are illustrated in Fig. 164*e*.

The *clevis* shown in Fig. 164*g* is a convenient form of end connection for round and square bars. Upset ends are usually provided, as explained in the previous paragraph. The pin in the clevis may be a *cotter pin*, as shown in Fig. 164*g*, or an ordinary bolt and nut. The small split pin inserted in the larger pin is called a *cotter*.

Adjustable Bars. It is often desirable to make tension rods and bars adjustable so that they may be tightened. Two devices are used for this purpose, the *turnbuckle* shown in Fig. 164*d* and the *sleeve nut* shown in Fig. 164*f*. In both devices a right-hand thread is used at one end and a left-hand thread at the other so that the ends of the bar may

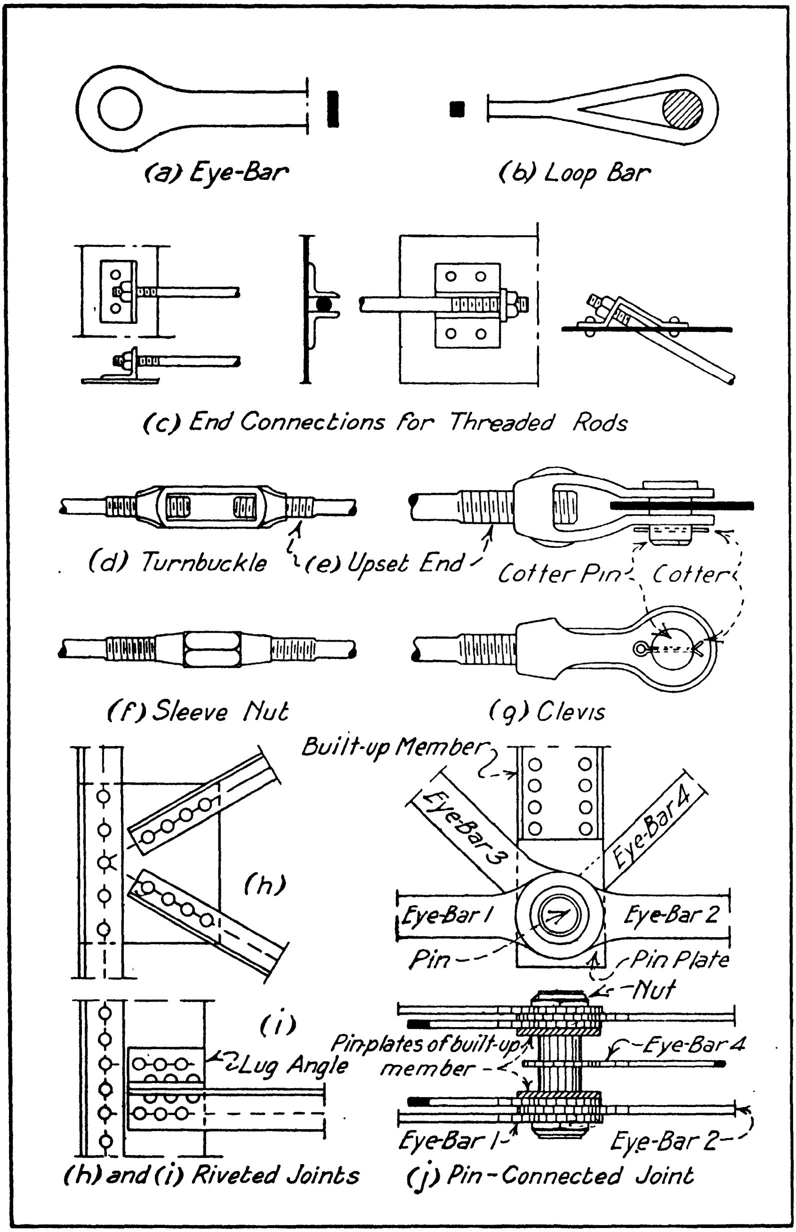


FIG. 164. End Connections for Steel Tension Members

be drawn together or pushed apart by turning the turnbuckle or sleeve nut in the proper direction.

Connection or Gusset Plates and Riveted Joints. Tension and compression members composed of angles, channels, and various forms of built-up members usually have their ends riveted to plates called *connection* or *gusset plates.* The number of rivets required is determined by the stress in the member. The end connection of a member composed of a single angle is shown in Fig. 164*h*. The use of a *lug angle* shown in Fig. 164*i* is sometimes desirable. The detail drawing of a roof truss shown in Fig. 144*b* will illustrate the use of connection or gusset plates.

Pin-Connected Joints. The joints at the points of intersection of the members of a truss are usually formed by riveting the various members to connection or gusset plates as just described. Another form of joint which has a limited use is the pin joint illustrated in Fig. 164*j*. The various built-up members may be riveted to separate plates which are connected by a pin. These plates are called *pin plates.*

Beam and Girder Connections. The usual method for connecting beams to girders is with *framed connections,* as illustrated in Fig. 165*a*. The size of angles and the number of rivets to be used for each size of beam has been standardized to quite an extent and such connections are called *standard connections.* One angle is sometimes used instead of two. Very often it is necessary to keep the top flanges of the beam and the girder at the same elevation. In this case, the beam flange must be cut to clear the flange of the girder, as shown in Fig. 165*b*, and the beam is said to be *coped.* In many cases the beam may rest on top of the girder and the only connection required is bolts through the flanges, as shown in Fig. 165*c*, to hold them together. Channel purlins are usually supported on the sloping top chords of roof trusses by means of the *clip-angle connection* shown in Fig. 165*d*. This connection may be bolted instead of riveted if desired.

Connection of Beams and Girders to Columns. There are two types of connections used between beams or girders and columns, the *framed-connection type* and the *seated type.*

The framed-connection type illustrated in Fig. 165*e* consists of two angles which are riveted to the beam or girder in the shop, the rivets between the angles and the column being driven in the field. A *shelf angle* may be provided to support the beam or girder during erection. This is called an *erection seat.*

The seated type of connection shown in Fig. 165*f* consists of an angle at the bottom side of the beam which is shop-riveted to the column and an angle at the top which is field-riveted to the beam and

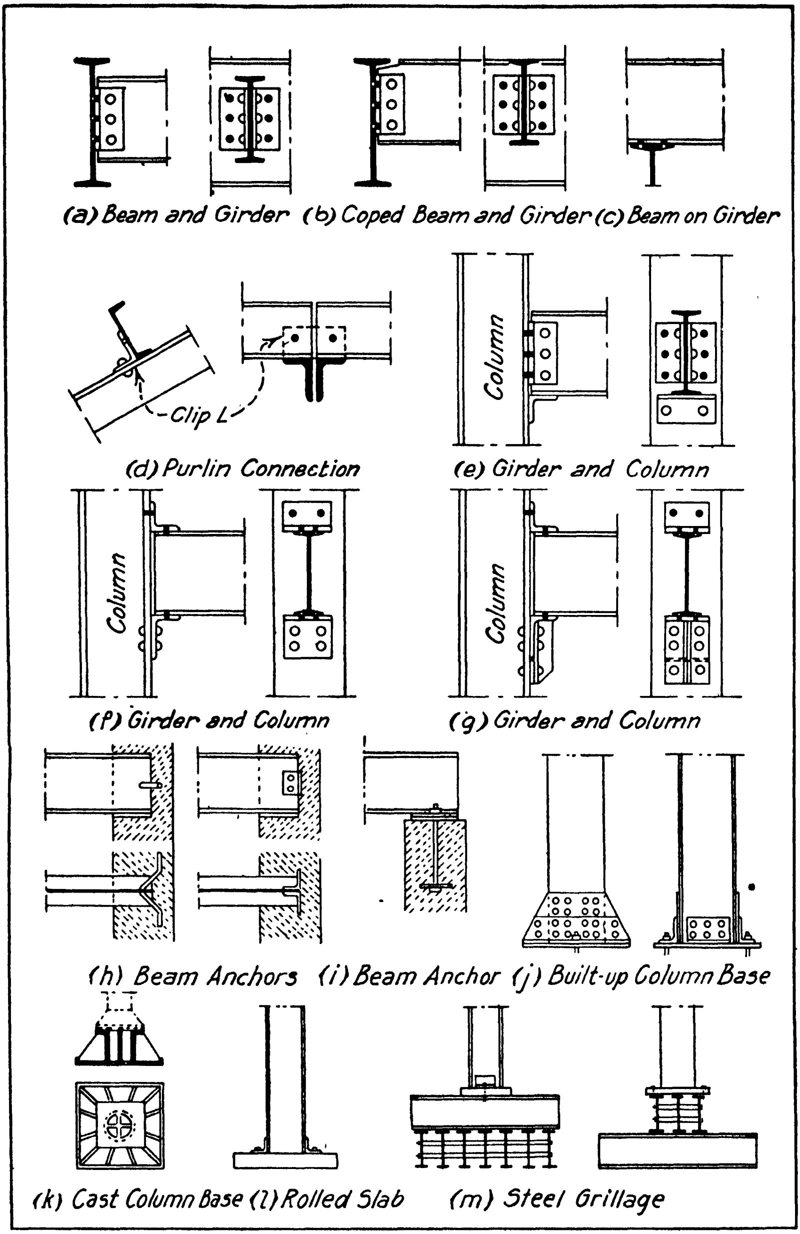


FIG. 165. Beam-End Connections and Column Splices

column. For large reactions it is necessary to provide one or two *stiffener angles* to support the outstanding leg of the bottom angle, as shown in Fig. 165*g*.

The shop work is simpler on the seated type and fewer field rivets are required, but this type may project through the fireproofing if used in connecting to column flanges, and then the framed connection is used.

Wall Supports for Beams and Girders. Steel beams and girders may be built into masonry walls. *Bearing plates* are provided to distribute the reaction over a larger area, and anchors shown in Fig. 165*h* tie the beam and wall together. Where beams and girders are not built into the wall, *anchor bolts* shown in Fig. 165*i* are provided.

Column Bases. The load at the lower end of a column must be transferred to a concrete footing or pier which in turn transfers the load to the ground. If the end of the steel column were permitted to rest directly on the concrete, the concrete would be crushed where the two came in contact because the working stress in the steel is much greater than the strength of the concrete in bearing. It is therefore necessary to distribute the column load over a large area of the footing. This is done by means of the *column base*. Bases for steel columns may be divided into four classes:

1. Built-up bases made from structural sections, as shown in Fig. 165*j*.
2. Cast bases of steel or cast iron, as shown in Fig. 165*k*.
3. Rolled-steel slabs, as shown in Fig. 165*l*.
4. Steel grillages, as shown in Fig. 165*m*.

Built-up bases are suitable for light loads, but where it is necessary to distribute the column load over a considerable area the cast-iron or cast-steel bases may be used, cast steel being much stronger and more reliable than cast iron. These are rarely, if ever, used. Rolled-steel slabs have come into general use. They are more economical and reliable than the cast-iron bases and more economical than the cast-steel bases. The end of the column is milled and bears directly on the steel slab. A simple connection is made between the column end and the slab by means of two angles. Slabs are available up to 12 in. in thickness, but slabs over 6 in. thick are not usually economical.

The following statements concerning column bases are taken from the Engineering Standards of the American Bridge Company:

Rolled-steel slabs, instead of beam grillages, should be used where the required length of beams is 3 ft. or less. In general, preference is to be given to the use of slabs bearing directly on the concrete.

Single-tier grillages should be used in preference to double-tier grillages.

Column bases with wing-plates and stiffeners should not be used.

Slabs 4 in. thick or less may be straightened true and smooth in the hydraulic press. Slabs over 4 in. thick should be planed where the surface has a steel bearing. Surfaces bearing on concrete need not be planed; but, in order that slabs may be set true and level, proper allowance should be made for grouting between slabs and concrete.

Wind Bracing for Mill Buildings. Buildings must be designed to resist the lateral forces due to wind as well as the vertical forces due to the weight of the buildings and their contents. Provision must also be made for the lateral thrust of cranes and other equipment.

A simple steel mill building frame with lateral bracing omitted is shown diagrammatically in Fig. 166*a*. The steel frame for a building with three-hinged arches is shown in Fig. 166*b*. The arches are braced in pairs as shown by broken lines. Several types of steel mill building frames are shown in Fig. 166*c*. These are provided with lateral bracing as described in the following paragraphs. Three types of wind bracing are used in steel mill buildings. The simplest type makes use of *knee braces* to brace the columns rigidly to the trusses, as shown in Fig. 167*a*, or trusses with considerable depth at the ends are rigidly fastened to the columns, as shown in Fig. 167*b*. This type of construction provides bracing to resist wind forces on the sides of the buildings, but wind forces against the ends of the buildings are resisted by *cross bracing* in the plane of the sides or by a rigid lattice girder just below the eaves, as will be explained in the next two methods.

Another method of bracing steel mill buildings to resist wind forces consists of providing cross bracing in the plane of the bottom chord of the truss to make the building rigid from end to end, in this plane. In addition to this bracing the sides and ends are made rigid by *diagonal bracing* so that the whole structure acts like a rigid box. This method of bracing is shown in Fig. 167*c*. It is not necessary to provide diagonal bracing in all the *bays* (spaces between columns) on the sides. Bracing is also provided in the plane of the top chord to hold the tops of the trusses in position, but this bracing is not essential to the wind bracing system and so it is not shown in the figure. It is evident that this system might interfere seriously with the windows and doors.

A third system provides lattice girders in the sides and ends to make them rigid. The bracing in the plane of the bottom chord is the same as in the previous method. See Fig. 167*d*.

The steel frame of a foundry building and also the completed building are shown in Fig. 168. Steel arch frames for hangars are shown in Figs. 150 and 151. The frame in Fig. 151 was covered with asbestos-protected metal, as described in Art. 70.

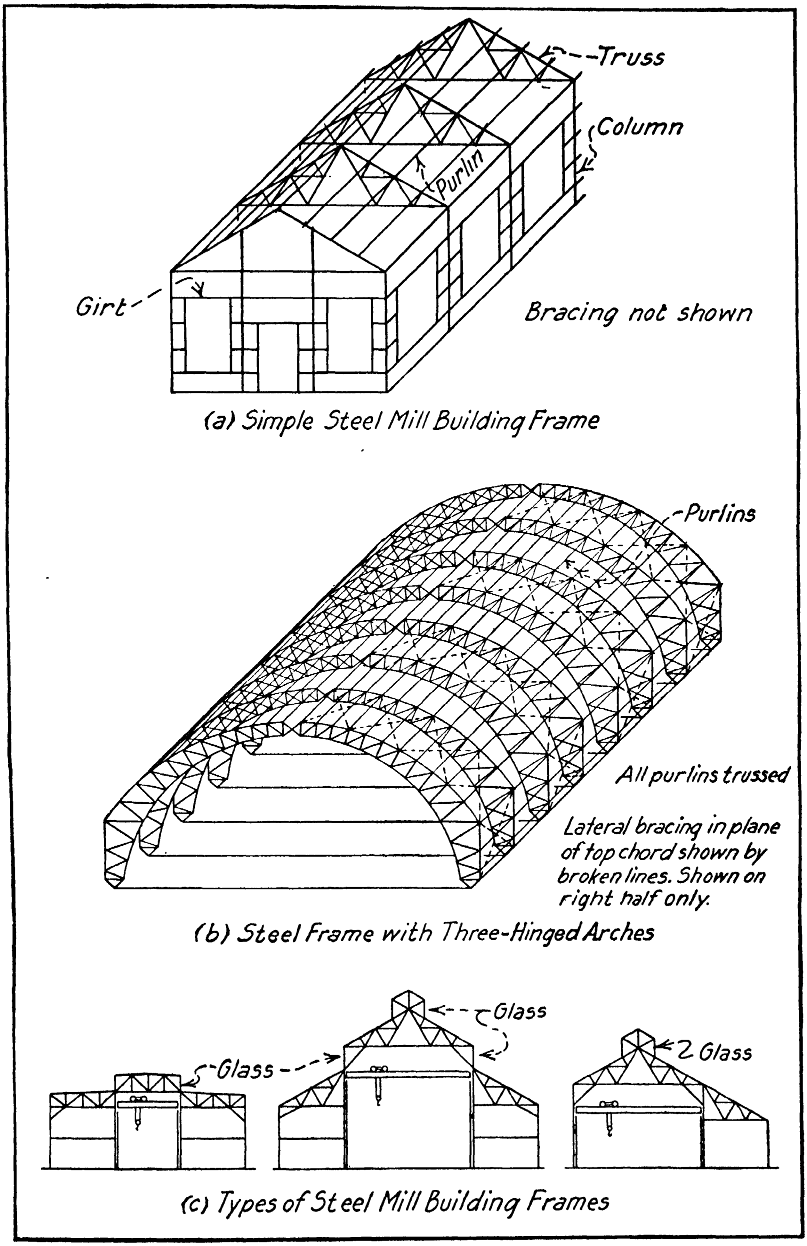


FIG. 166. Framing for Steel Buildings

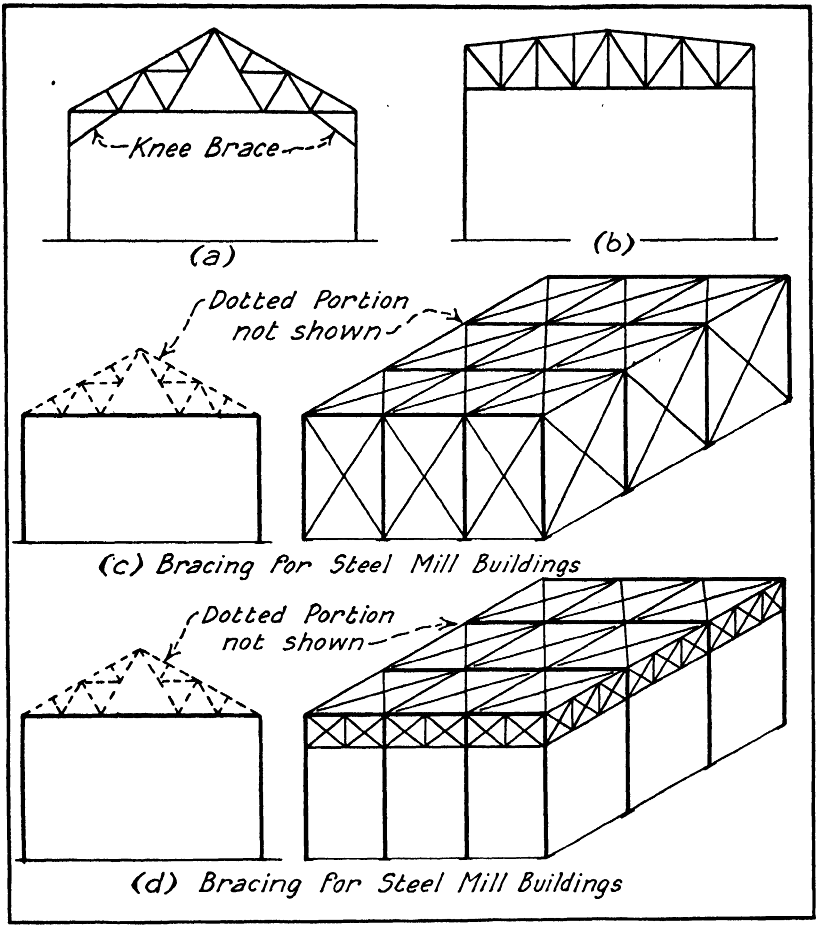
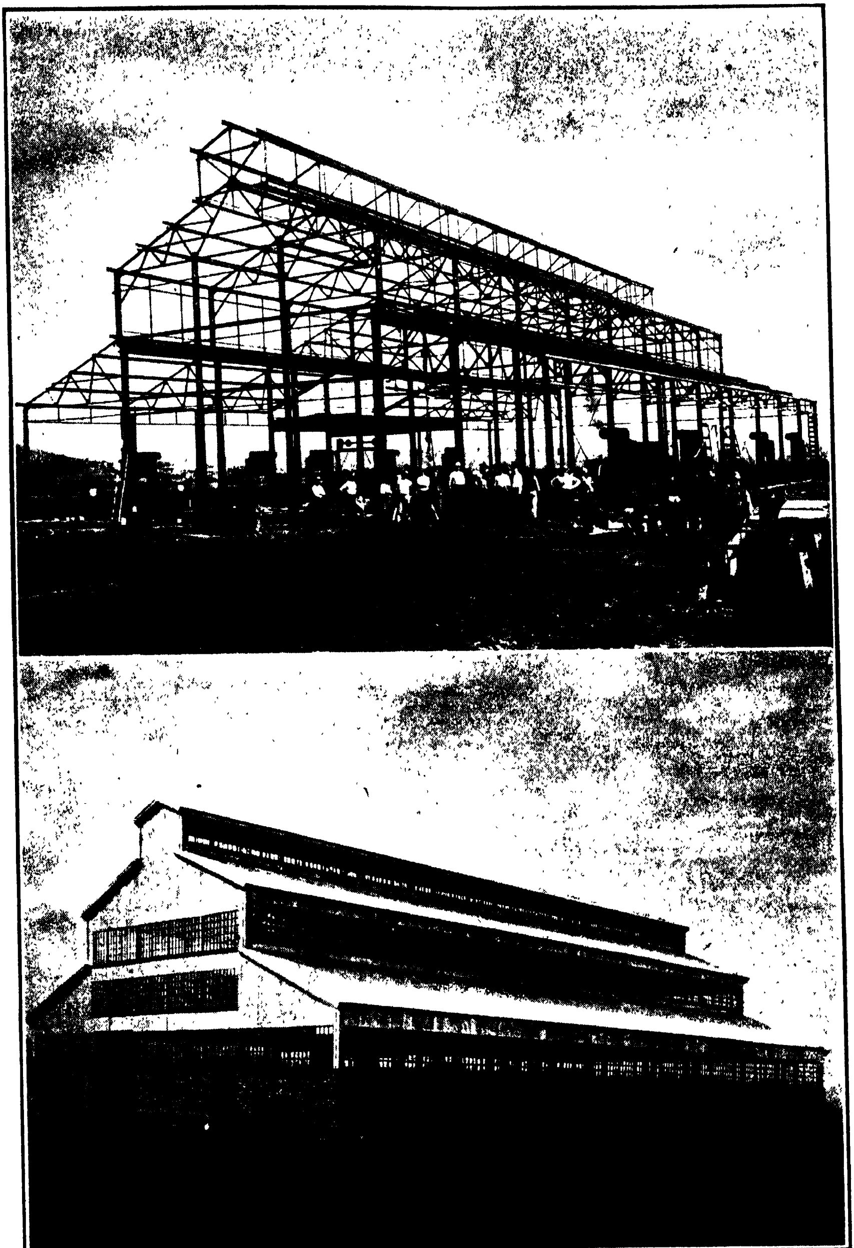


FIG. 167. Wind Bracing for Steel Mill Buildings

Wind Bracing for Tall Steel Buildings. In tall buildings of skeleton construction such as office buildings the providing of adequate bracing to resist wind is an important feature of the design. If a frame as illustrated in Fig. 169*a* is subjected to lateral forces such as those due to wind, it would collapse by distorting as in Fig. 169*b*. In low buildings of considerable width the stiffening effect of the panel walls and partitions and the rigidity of the joints between the girders and columns may be sufficient to provide satisfactory resistance to wind forces, but this is not true of tall buildings. Some codes state that



Kansas City Structural Steel Co.

Fig. 168. Foundry Building showing Steel Frame and Completed Structure

buildings less than 150 ft. in height whose least width is greater than one-fourth the height need have no special provision for wind. Others place the limit of height at 100 ft. and require that the least width be one-third the height in order that the effect of wind may be disregarded. The magnitude of the wind load is considered in Art. 3.

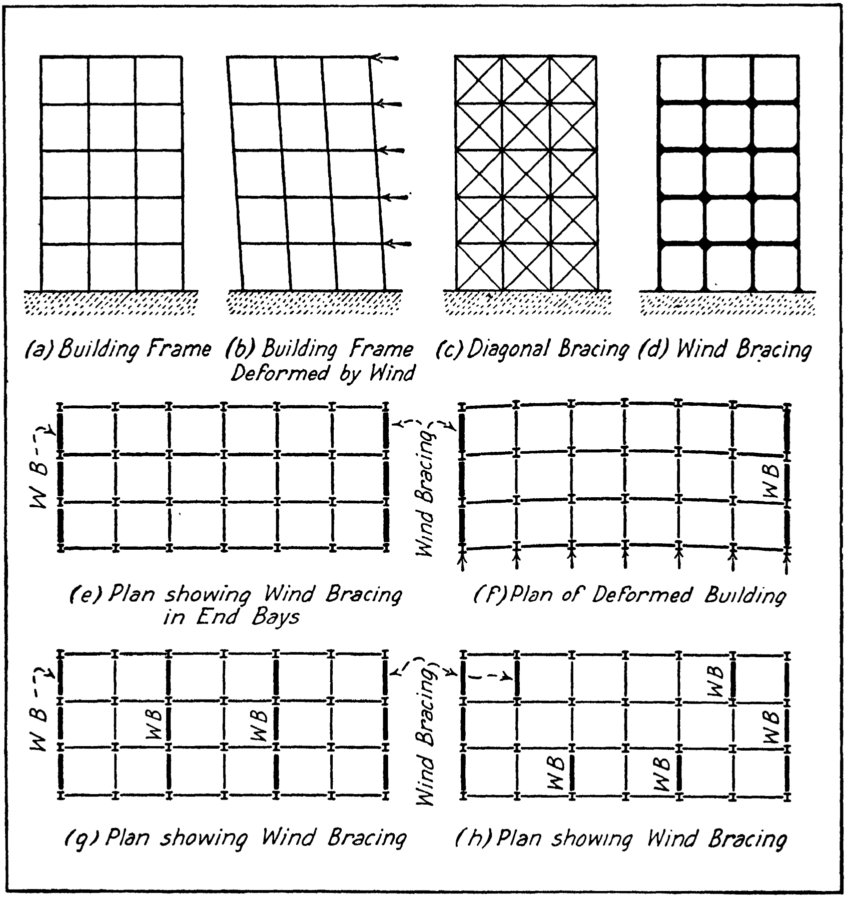


FIG. 169. Wind Bracing for Steel Office or Tier Buildings

In the design of tall buildings the structural frame is usually considered as carrying the entire wind load, but some building codes and some engineers consider that the walls and partitions will carry a part of this load, leaving only the remainder to be carried by the structural frame.

Several types of wind bracings have been devised. The most direct type consists of diagonals crossing the vertical panels between the columns and the floor girders, as shown in Fig. 169*c*. It is evident, however, that this method is limited in its application because of its interference with the use of the building and with the locating of windows and doors, even though it is necessary to brace only a relatively small number of panels, as will be explained later.

If sufficiently rigid connections are provided between the girders and columns as shown in Fig. 169*d*, a skeleton frame will be able to resist lateral forces. It is evident that there is a tendency to bend the columns and girders when this type of bracing is used; so it is necessary to consider the bending stresses in the design of these members. This type of wind bracing can be so arranged as to interfere very little with the design and the use of a building.

The group of braced vertical panels in a single vertical plane designed to resist wind stresses is called a *wind bent*. It is not necessary to make all panels of a building rigid, although this may be desirable as it reduces the size of the bracing. As a rule, wind bents can be placed in the outside walls, as shown in Fig. 169*e*, more conveniently than elsewhere. With this arrangement, the floors of a building tend to deform, as shown in Fig. 169*f*, under the action of wind forces. The floors used in modern building construction are usually rigid enough to carry the wind load to the wall bents but, if they are not, special bracing can be provided in the plane of the floors. It may be undesirable or impossible to place all the required wind bracing in the outside bents of a building, in which case some of the interior bents must be utilized. It is desirable but not necessary for these to be continuous across the building, as shown in Fig. 169*g*, but wind bents may be distributed throughout the building, as shown in Fig. 169*h*, each being designed to carry its part of the wind load. They should be so placed that there is no twisting effect in the frame due to greater rigidity on one side than on the other and due consideration must be given to relative lateral deflections.

In buildings which diminish in size in the upper stories, wind bents located in the exterior walls may be continued down through the interior of the lower part of the building or, in some cases, it may be desirable to transfer the wind loads to wall bents in the lower stories, as shown in Fig. 170*a*. The horizontal effect of the wind on the upper section may be transferred to the wall bents or other bents in the lower stories by means of a heavy concrete floor slab where the building changes section, or by special bracing in the floor. The vertical reactions of the columns of the wind bents are transferred directly down through the corresponding columns in the lower section.

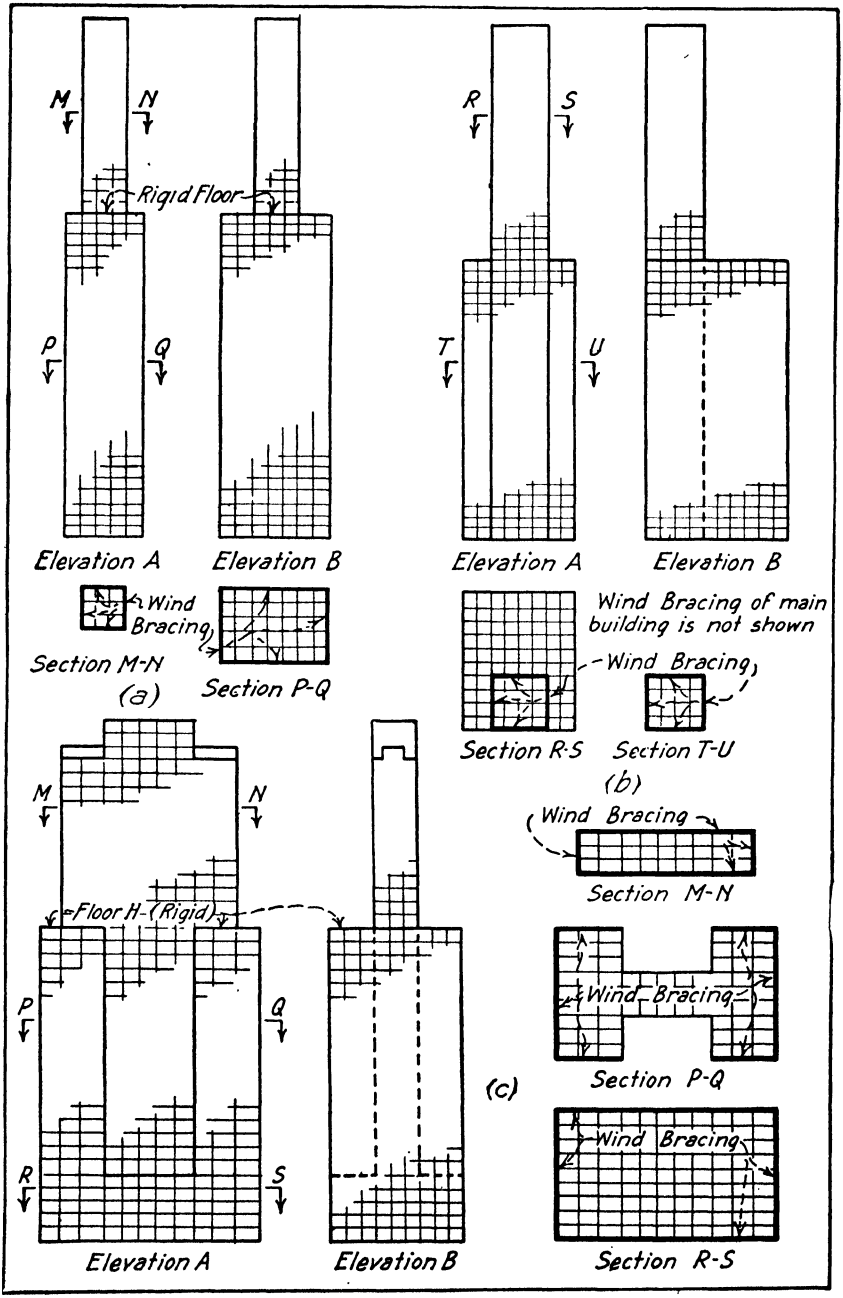


FIG. 170. Wind Bracing for Steel Office or Tier Buildings

In buildings with towers projecting above a relatively low and broad main building, the towers are usually provided with wind bracing which is independent of the main structural frame, as shown in Fig. 170*b*. The tower bracing may be in the exterior bents only or in the interior bents also.

Buildings of irregular shape and buildings which change in section require special study. The system of bracing shown in Fig. 170*c* has been used on such buildings. No wind bracing is required for the upper floors. From sections *M–N*, *P–Q*, and *R–S* it is seen that the wind bracing is all placed in the outside walls but all outside walls do not contain wind bracing. The horizontal thrust on the portion of the building above floor *H* is transmitted to the wind bents in the outside walls below floor *H*. In order to transmit this horizontal thrust, floor *H* must be specially designed. The vertical wind loads in the columns above floor *H* are transmitted directly down the same columns below floor *H*.

In a report on " Wind Bracing in Steel Buildings " by a committee of the American Society of Civil Engineers appearing in the February, 1932, *Proceedings* of that Society the following comments are made:

Ordinary connections between beams, girders, and columns furnish a certain amount of rigidity to the frame. By increasing the capacity of these connections with the use of heavily riveted clip angles on the top and bottom of the horizontal member, or by using sections of I beams in place of the angles, connections of considerable strength may be obtained. In this report these will be referred to as *knuckle connections*. Their action is to prevent distortion of the panels when horizontal force is applied. Analysis will show, however, that bending moments result in the columns and beams or girders, which in high or very narrow frames will mean considerable deflection in the building from *web distortion* alone.

The obvious advantage of knuckle connections is the ease of adapting them to conditions where diagonal-bracing members would be objectionable in a building. In high or narrow frames, however, the inability to hold deflection within reasonable bounds without greatly increasing the column and beam or girder sections with such connections makes it very desirable to adopt *diagonal bracing* of some kind.

When using diagonal bracing, which naturally interferes to some extent with headroom, passageway, or window spaces, it is usually necessary to concentrate the resistance to horizontal force in certain panels or bents of the building where their use will not seriously affect the plan. The outside walls usually offer such an opportunity. Other chances occur between elevators and around permanent shaft or service areas. Frequently, particularly in set-back buildings, lines can not run continuously from top to bottom of the building. This does not create serious difficulty, however, as provision for horizontal transfer of shears can usually be made in the floor construction at

the offset level. In the arrangement of diagonal bracing the designer can often exercise considerable ingenuity so as to avoid necessary passageways and openings. Common arrangements are indicated in the diagrams of Fig. 171.

If each bent which is to carry wind is pictured as a vertical truss, with the columns forming chords and the floor members the web posts, the most natural and effective way to complete the web system is to add diagonals crossing the panels. The most effective and economical bracing will approach this simple solution.

It is often necessary to use one type in one panel of a bent and another type in adjoining panels. This offers no great difficulty, but analysis must be based on equal web deflections in such panels so that the bent may work as a unit,

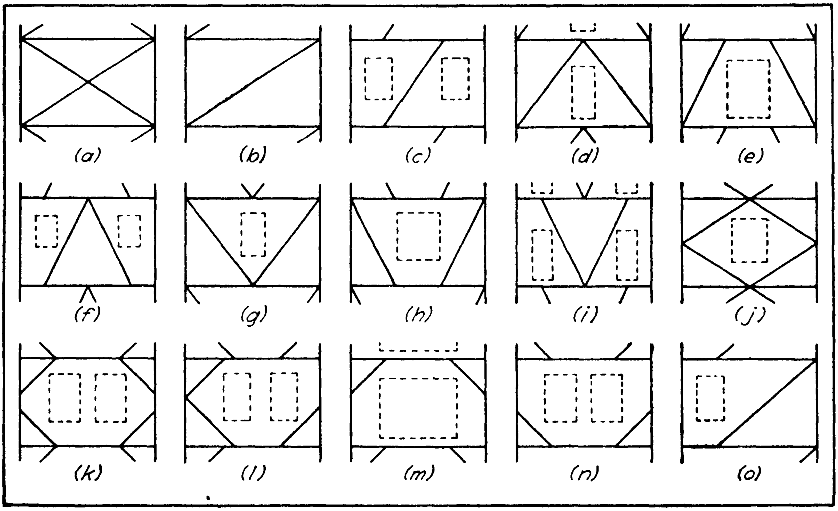


FIG. 171. Diagonal Wind Bracing for Tall Buildings

as assumed. It will usually be found difficult to combine such extremes as a knuckle-braced panel with a full diagonal-braced panel in the same bent or line. Without great waste of material the knuckle panel can hardly be made stiff enough to take any considerable load in comparison with the fully braced panel.

Deep-riveted *gusset-plate connections* have been used in many wind designs, and still are used. To obtain a rigidity equal to that of a diagonally braced panel, however, usually requires more material and many more rivets in such a type, with consequent loss of economy.

Joint Details. Various types of joints between wind girders and columns are illustrated in Fig. 172*a* to *f*. The simple connection in Fig. 172*a* may be used when the moment is small. It can be used on interior connections as well as on exterior connections as it does not

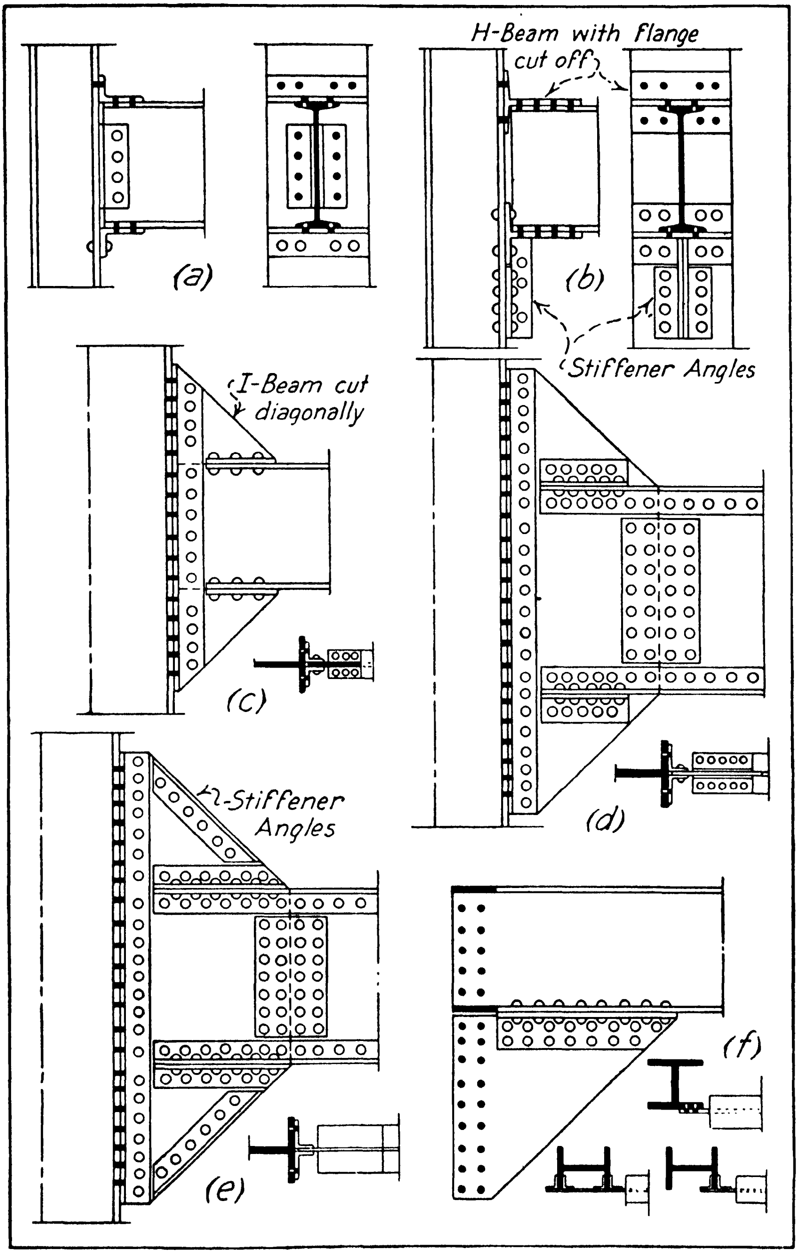


FIG. 172. Ordinary, Knuckle, and Gusset-Plate Connections

occupy any space. The knuckle connection shown in Fig. 172*b* will develop considerable resisting moment and occupies very little space. The connecting members are structural tees cut from wide-flanged sections.

A framed connection can be used with this detail in place of the seated connection shown. The connection shown in Fig. 172*c* is sometimes used. The brackets are I beams which have been cut diagonally. A triangular plate and a pair of angles can be substituted for each I beam bracket and a plate girder can be substituted for the I beam. The connection shown in Fig. 172*d* can be used to develop large resisting moments. A single plate is used to form both brackets and replace a part of the web of the girder. This requires the use of splice plates as shown. The connection shown in Fig. 172*e* is similar to that in Fig. 172*d*, except that stiffener angles are provided along the edges of the bracket to prevent buckling. Conditions may not permit the use of a top bracket. In this case, the detail shown in Fig. 172*f* may be used. This connection to the column is different in this detail than that shown in the other figures but the two connections can be interchanged on all the types. Several methods used in connecting this type of connection to a column are shown in Fig. 172*f*. The connections shown in Fig. 172*d* and 172*e* can be altered so as to have a bottom bracket only to correspond with the connection in Fig. 172*f*, and all three types may be changed so as to have top brackets instead of bottom brackets. The connections in Fig. 172*d* to *f* are called gusset-plate connections.

In tall slender buildings the wind moment may place tension in some of the columns. These stresses must be provided for in the design of the column splices, in anchoring the columns to the foundations, and in the design of the foundations.

Earthquake Resistance. The stresses produced by earthquake shocks are usually considered proportional to the weight of a building and its contents, and not to the surface area as in wind stresses; so the assumption that a building designed to resist wind loads will also resist earthquake shocks is without foundation. As stated in Art. 3, a wind load of 20 lb. per sq. ft. of exposed wall area is considered adequate for buildings up to 300 ft. high. In areas subject to earthquake shocks, an authoritative requirement for buildings on good foundations is a lateral load equal to 7½ per cent of the weight of the building and contents. The weight of fireproof buildings of skeleton steel construction is about 20 lb. per cu. ft. The lateral force required for satisfactory earthquake resistance is therefore $0.075 \times 20 = 1\frac{1}{2}$ lb. per cu. ft. This would equal the wind-load requirement for a building with a horizontal

dimension of only $20 \div 1\frac{1}{2} = 13.3$ ft. measured in the direction of the wind. For a building 50 ft. wide the lateral force required to resist earthquake shocks under the conditions given would correspond to $50 \times 1\frac{1}{2} = 75$ lb. per sq. ft. of exposed wall area. Such loads have a pronounced influence on the design of buildings.

In an article in the *Engineering News-Record*, Vol. 100, p. 699, Henry D. Dewell gives the following fundamental principles of design:

Certain essential features of earthquake-resistant construction which are generally recognized by those who have given study to the subject will be set forth. These are applicable to all types of buildings.

Location. Disadvantageous locations are (1) proximity to an active fault plane, (2) made or marshy land and (3) the junction between soils which would act differently in an earthquake shock, as the top of a bluff or the bottom of a slope. Conversely, a location at some distance from the active fault plane, and on hard rock or good firm deep soil, with approximately level surface, is most advantageous.

Shape of Building. The building that is " closed " in plan, as a hollow or solid rectangle, is best from the standpoint of seismic risk. Buildings of L or U shape are at a disadvantage in an earthquake, for the component parts would likely have different vibration periods, resulting in heavy stresses at the junction of the parts. Finally, uniformity as opposed to irregularity of height is a desideratum.

Foundations. Deep foundations are a valuable asset in an earthquake. Foundations should be substantial in design and well tied together. All concrete foundations should be well reinforced, and the reinforcing from one unit should be carried well into connecting units. High soil pressures should be avoided, and particular attention should be given to the corner piers, to give them ample bearing area against the earthquake effects which are there concentrated.

Superstructure. The superstructure should be built to give, in effect, a unit mass against earthquake. Rigidity is essential. Full diagonal bracing should be used when possible, and deep knee-bracing when openings will not permit full diagonals. The walls should be carefully designed, heavily reinforced around openings, which should be as few as possible. Solid panels on either side of a corner add great resistance to the wall. Veneers of stone or brick should be avoided, but if absolutely necessary should be thoroughly tied and anchored to a rigid backing.

General. Buildings with towers or heavy cornices and buildings with very unequal distribution of mass are at a decided disadvantage in an earthquake. The various units, having different natural periods of vibration, tend to batter against one another; the result is almost certain destruction, unless these units are properly framed to resist such action.

Buildings or parts of a building that are in contact but not bonded firmly together may sway with different periods. In that case they are likely to separate and come together again with some degree of violence, sufficient to

destroy them. It is therefore important that structures should be symmetrical in design and in distribution of weight. Where that ideal is impracticable, the unsymmetrical sections should be firmly tied together so that they will swing as a unit, or else they should be separated beyond the range of collision and connected (where connection is necessary) only by lighter and more fragile structures in which damage may be safely and economically concentrated.

The following recommendations made by Dr. T. Naito of Waseda University, Japan, are quoted in Mr. Dewell's article:

(1) That reinforced-concrete walls, particularly with diagonal reinforcing, be used when possible; (2) that the corner bays of buildings have as few openings as possible; (3) that the full depth of wall spandrel sections be utilized as beams; (4) that structural steel wall columns of I and H shape have their webs always placed parallel with the walls; (5) that end restraint additional to that furnished by their connections to columns be given the beams on column center lines, by means of extra reinforcing bars in the concrete floor slab across the column; (6) that horizontal diagonal bracing be used between the floor beams attaching to an interior column; (7) that particular attention be given the corner wall columns of a building, because such columns act as flanges of the vertical cantilever beams represented by the walls, and hence will carry heavy direct stress in an earthquake; (8) that for a similar reason, ample area to carry these column loads be given the footings of such corner columns, and (9) that foundation footings be well tied together.

Steel Frame. A partially completed office building with a steel frame is illustrated in Fig. 173, and the completed building in Fig. 174. The frame of a building of the office building type formed by assembling the various beams, girders, and columns is illustrated in Fig. 175. In this frame no special provision has been made for wind bracing. The following points should be noted:

1. The outside wall, called a panel or inclosure wall, is supported at each story by the spandrel beams which transmit their load to the outside columns.

2. The panel walls shown are veneered with stone ashlar 3¾ in. thick which is bonded to the backing by a bond course 7½ in. thick every third course and by anchors which are provided at the intermediate joints. The backing may be of brick or of hollow tile. The anchors are galvanized after bending. One bond course rests on the spandrel beam.

3. The floor beams are placed at the third points of the girders where they cause the least moment. They are connected to the girders by framed connections.

4. The floor beams are attached to the columns by seated connections. Framed connections can be used if there is room to get them in.

5. Framed connections are used between the girders and columns. Seated connections can be used if the stiffener angles can be small enough so that they will not project through the fireproofing.

6. Wide-flange section columns are used. The columns are continuous through two stories. Sometimes columns continuous for three stories are used.

7. The column splices are located about 2 ft. above the floor.

8. Reinforced-concrete floor slabs supported by steel beams are shown. Many other types of floor, as described in Art. 55, might have been used.

9. The supports for the columns are not shown. The columns would rest on slabs or grillages which would spread the column load over concrete footing or piers.

10. All steel members are fireproofed.

Typical Framing Details. Typical details of office building construction with built-up plate and angle columns are shown in Fig. 176*a*. The points which should be noted are:

1. The column is a built H consisting of four flange angles, a web plate, and two cover plates. The beam and girder connections for a wide-flange section column are the same as those shown in this figure, but the column details are simpler, as shown in Fig. 175. The wide-flange sections are more commonly used than the built-up sections.

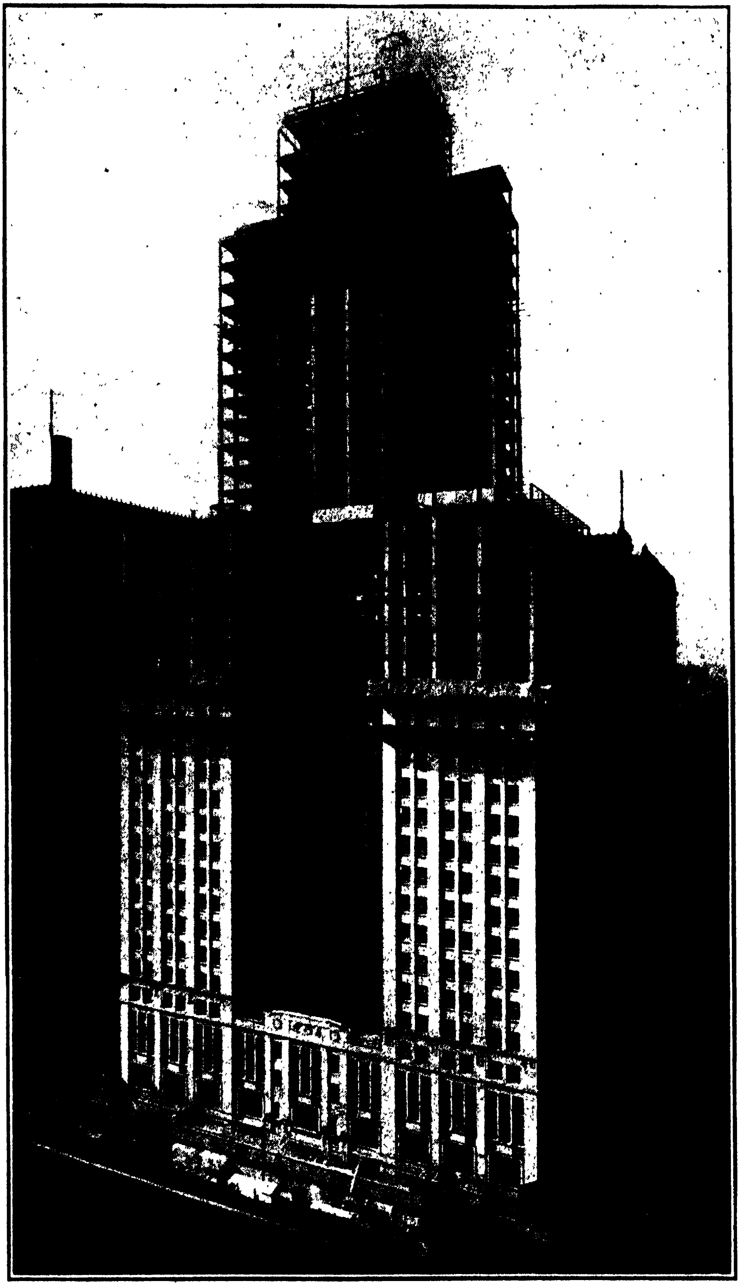
2. A built-up base is shown but slab bases as shown in Fig. 165*l* are more commonly used to distribute the column load.

3. Framed connections are shown between the floor beams and the girders.

4. Seated connections and framed connections are shown between the girders and the column. Either type might be used if there is sufficient clearance.

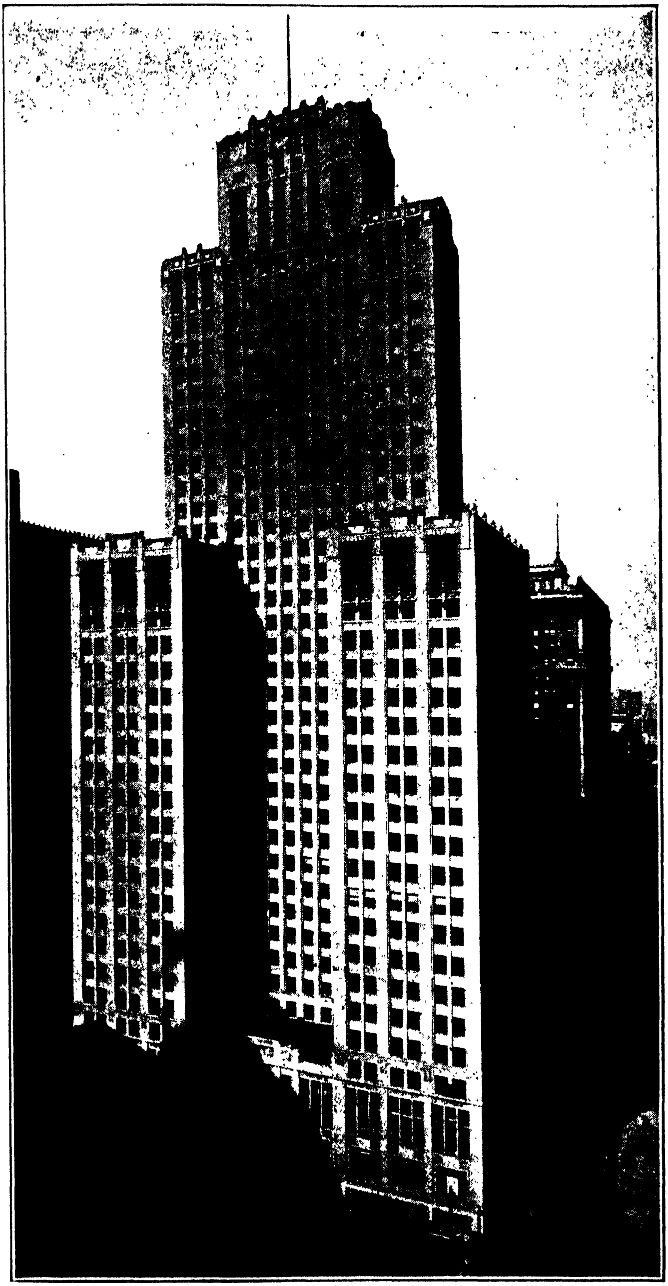
5. Erection seats are provided on the columns, when framed beam or girder connections are used. These seats are provided to support the beams or girders while temporary bolts are put in some of the rivet holes to hold the beams or girders in place while the first rivets are being driven.

6. Countersunk rivets are used in some places directly opposite the beams and girders so that they can be swung into place during erection. If button heads had been used these beams and girders could not be placed, for the rivet heads would interfere. In some cases, the rivets are countersunk on the near side to provide clearance for the girder which is on the near side of the column. In other cases, the rivets on



Dilks Construction Co., Builders *D. H. Burnham & Co., Architects*

FIG. 173. The Bankers Building, Chicago, Illinois



Dilks Construction Co., Builders *D. H. Burnham & Co., Architects*

Fig. 174. The Bankers Building, Chicago, Illinois

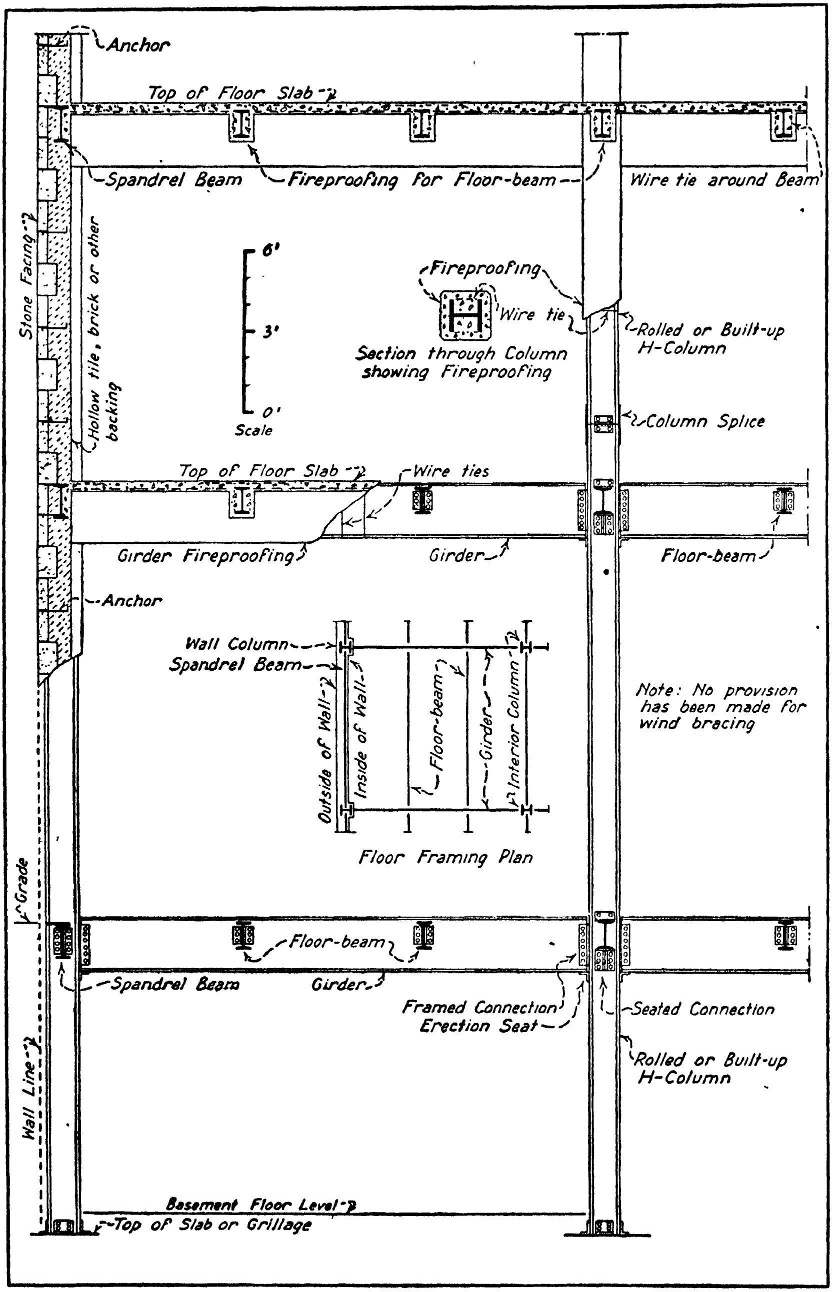


FIG. 175. Office- or Tier-Building Construction

the far side are countersunk to provide clearance for the girder on the far side.

7. The clip angle on the top flange of girders with seated connections is not shop-riveted to the girder or to the column but is field-riveted after the girder is in position. This procedure is followed for two reasons. If the clip angle were riveted to the column it would be difficult to place the girder when the connection is to the column flange and impossible to place it if the connection is to the column web. Girders are cut ½ in. or more short of the clear distance between columns. This is done because of the greater cost of more accurate cutting and because it provides clearance when placing the beam if the clip angles are not riveted to the flange of the beam. If the clip angles were riveted to the top flange, the distance between the backs of the clip angles on the two ends would have to equal the clear distance between the columns and no clearance would be provided. This condition exists in framed connections.

8. The column extends through two stories as is customary and is spliced about 2 ft. above the floor line.

9. The ends of the abutting columns are surfaced accurately by milling so that they get good bearing. The column stress is transmitted directly across the cut section by bearing. The splice plates serve only to hold the members in line.

10. Field rivets are provided in the splice plate and column just below the top of the column. This is done to permit the splice plates to be spread slightly when placing the upper column section.

Typical details of a mill building column are shown in Fig. 176*b*. The points which should be noted are:

1. The offset in the columns is to provide for the support of the crane runway. If the building were not provided with a crane, the column section would be constant.

2. The crane runway is centered over the inner flange of the lower section of the column. This is common practice but is not essential.

3. A knee brace is shown to resist the lateral forces due to wind and to the thrust of the crane when accelerating transversely while carrying a load or the thrust due to the lateral swinging of a load. Knee braces may be omitted if other lateral bracing, as shown in Fig. 167, is provided. If headroom is a determining factor, a design without knee braces would probably be used, for such braces must be sufficiently high to clear the crane.

4. Field rivets are provided just below the junction of the web plate of the column and the gusset plate of the roof truss. This enables the flange angles to be spread slightly to permit the gusset plate to enter.

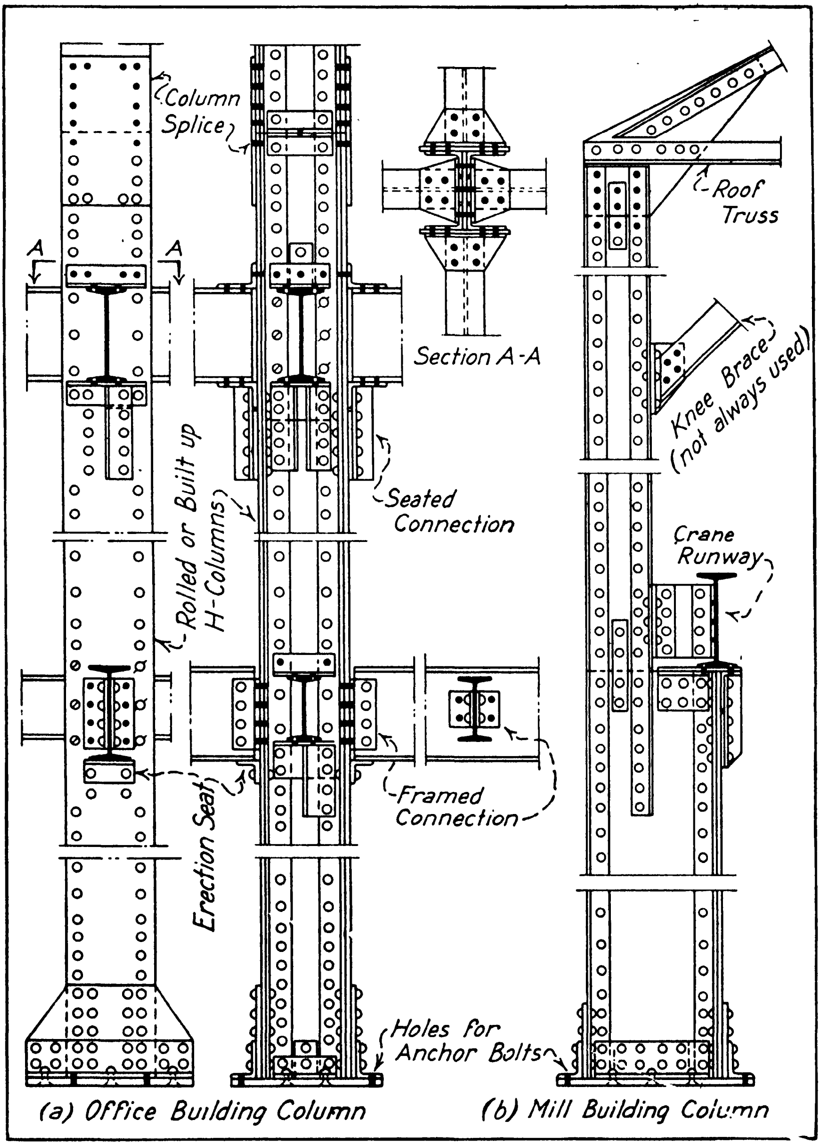


FIG. 176. Built-Up Steel Column Details

Fireproofing of Structural Steel. The classification of buildings according to construction is considered in Art. 2. The required fire ratings of the various parts of buildings in each class is given, these ratings being based upon the behavior of materials in a *standard fire test,* which is explained. The ratings must be sufficient to withstand the hazard involved. The minimum ratings for columns and girders in fireproof construction is 4 hours, and for beams 3 hours. In semifireproof construction, each of these is reduced by 1 hour.

The capacity of structural steel to carry stresses is considerably reduced at the high temperatures which may be expected to prevail during a severe fire. For that reason it is necessary to protect structural-steel members with fire-resistant materials. According to the 1938 " Building Code " of New York City, the thicknesses of fire-resistive materials, exclusive of air spaces, required to give various fire-resistive ratings are as follows:

THICKNESS OF FIRE-RESISTIVE MATERIALS

(For Protection of Structural-Steel Members for Various Fire Ratings, According to the 1938 " Building " Code of New York City)

Fire-Resistive Materials	Inches Required for Rating			
	4 hr.	3 hr.	2 hr.	1 hr.
Brick, burned clay or shale	3¾	3¾	2¼	2¼
Brick, sand lime	"	"	"	"
Concrete brick, block, or tile, except cinder-concrete units	"	"	"	"
Hollow or solid cinder-concrete block and tile having a compressive strength of at least 700 lb. per sq. in. of gross area	2½	2	2	1½
Solid gypsum block (to obtain 4-hr. rating must be plastered with ½ in. of gypsum plaster)	2	2	1½	1
Gypsum poured in place and reinforced	2	1½	1½	1
Hollow or solid burned clay tile or combinations of tile and concrete	2½	2	2	1½
Metal lath and gypsum plaster	2½	2	1½	⅞
Cement concrete, Grade I*	2	2	1½	1
Cement concrete, Grade II†	4	3	2	1½
Cement concrete, Grade II with wire mesh	3	2	2	1½
Hollow gypsum block (to obtain 4-hr. rating must be plastered with ½ in. of gypsum plaster)	3	3	3	3

* Grade I concrete has aggregate consisting of limestone, traprock, blast-furnace slag, cinders, calcareous gravel.

† Grade II concrete has aggregate consisting of granite or siliceous gravel.

The " Building Code " of the National Board of Fire Underwriters requires that the members of steel trusses in fireproof construction be protected by fireproofing materials to provide a fire-resistance rating of not less than 4 hours; but this protection may be omitted for steel trusses and from roof beams and purlins when the trusses support only roof loads and ceilings over floor areas having a clear height of not less than 25 ft. below the lower chords and when there is a con-

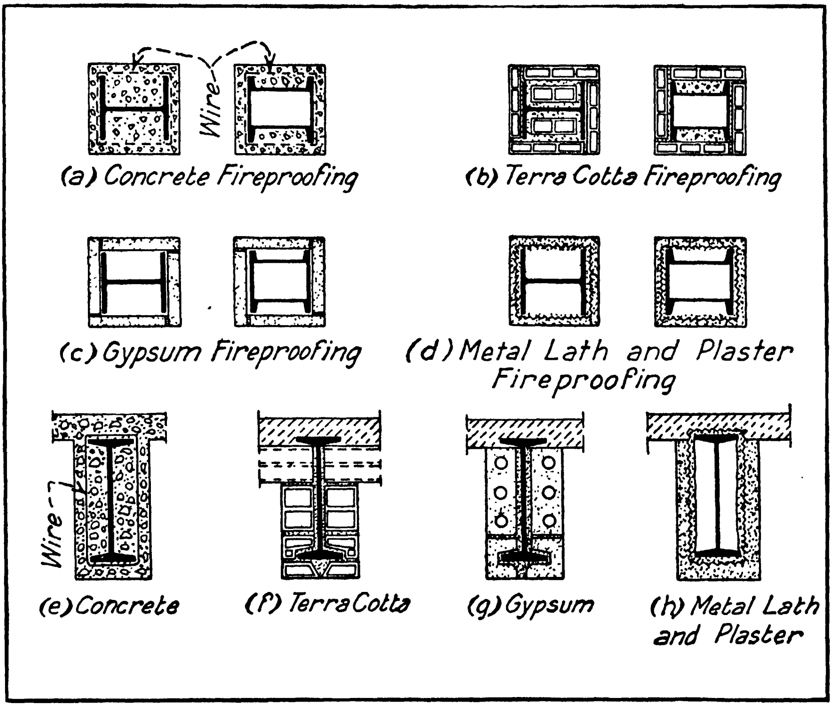


FIG. 177. Fire Protection for Steel Members

tinuous ceiling having a fire-resistance rating of not less than 1 hour, directly below and supported by the trusses, through which there are no openings unless they open into shafts or ducts to the roof, the enclosing walls of which have a fire-resistance rating of not less than 1 hour. In semifireproof construction, the trusses may be protected by a ceiling as described or they may be protected on the sides and below the bottom chords with expanded metal lath and gypsum mortar or cement mortar, not less than 1 in. thick.

The New York " Building Code " requires protection with material having a 3-hour and a 1½-hour rating for members of steel trusses in fireproof and fire-protected construction, respectively. All protection may be omitted from the members of trusses and from beams and purlins in 1-story structures and in multi-story structures this protection may be omitted when the trusses and other members support only roof loads, access passageways, or ventilating equipment, and have a clear height of at least 20 ft. below the lower chord of the trusses.

Methods of providing fire protection for steel columns are given in Fig. 177*a* to *d*, and steel beams in Fig. 177*e* to *h*.

ARTICLE 49. STEEL-STUD PARTITIONS AND CORRUGATED SIDING

Metal Lath on Metal Studs. Hollow partitions may be made by wiring metal lath to both sides of steel studs 12 to 16 in. apart and covered with plaster, as shown in Fig. 178*a*. The various forms of metal lath are described in Art. 74. The common form of hot-rolled structural channels is too heavy and therefore too costly to use for studs whose depth is over 1 in. Special cold-formed channels made of sheet steel bent to form the channel section are usually used. They may be obtained provided with prongs for holding the metal lath, as shown in Fig. 178*b*. The common depths of cold-formed channels used for hollow partition are 2, 3, and 4 in. Studs are obtainable which are built of two ¾-in. channels fastened together at intervals, as shown in Fig. 178*c*. This form of construction is illustrated in Fig. 178*d*. Its fire-resistive rating is given in Art. 24.

Exterior walls sometimes use this type of construction, in which case the outer surface is back-plastered.

This type of construction may be used for bearing walls or partitions for light loads.

Metal Lath and Plaster Solid Partitions. Solid partitions 1½ in. or 2 in. thick are constructed of studs ¾-in. or 1-in. channels, spaced 11¾ in. or 15¾ in. to allow for end lap, to which metal lath is wired on one side and plaster applied on both sides, as shown in Fig. 178*e*. The metal lath is placed with its greatest dimension horizontal; sheets are lapped at least ½ in. on the sides and wired together at one point between the studs; sheets are lapped at least 1 in. on the ends and are wired at 6-in. intervals along the stud. The channels are held in place by springing into holes drilled into the floor and ceiling in concrete construction. On wood floors the channels are bent to an angle and spiked. Integral lath may be used instead of the ordinary lath and channel studs. This type

of construction is not used for bearing partitions. Its fire-resistive rating is given in Art. 24.

Plaster Board on Metal Studs. Hollow partitions may be made by plastering on plaster board fastened to both sides of metal studs spaced 12 to 16 in. apart. This type of construction is illustrated in Fig. 178*f* and is used only for non-bearing partitions.

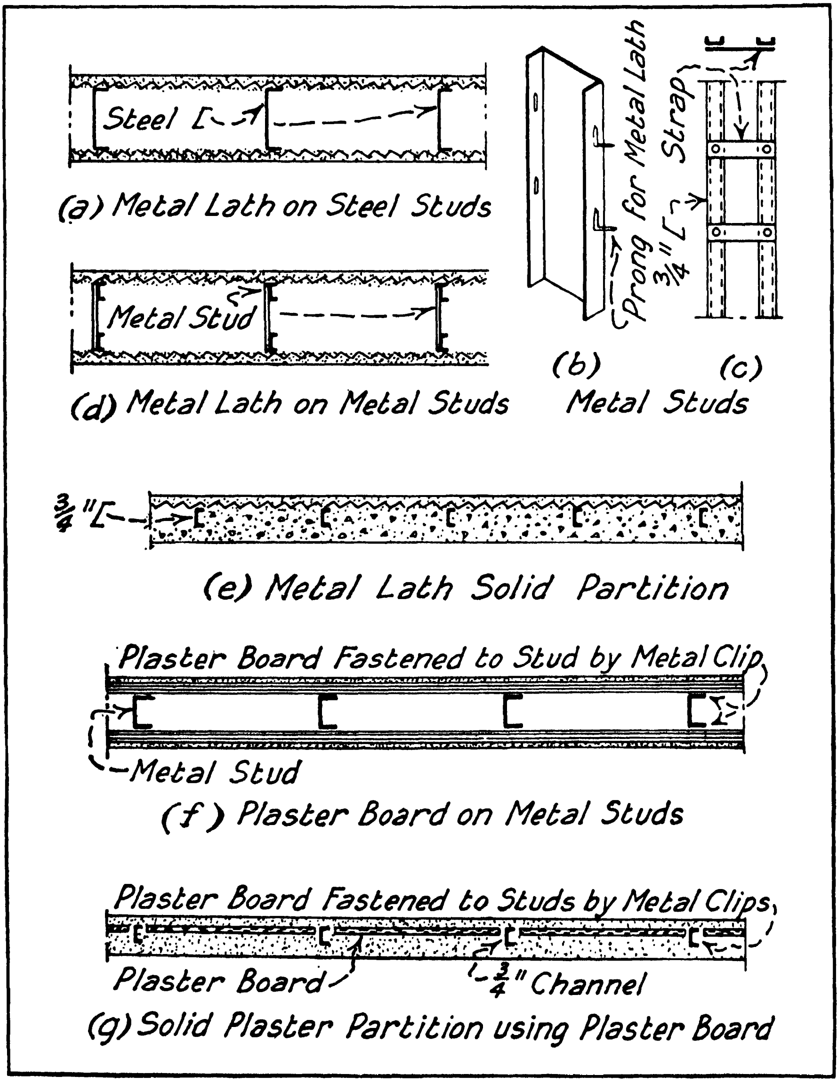


FIG. 178. Hollow and Solid Steel-Stud Partitions

Solid Plaster Partition Using Plaster Board. Solid partitions 2 in. thick may be made by plastering both sides of plaster board fastened, by special clips, to ¾-in. or 1-in. hot- or cold-rolled steel channel studs spaced 24¾ in. apart, as shown in Fig. 178*g*, and securely fastened to the floor and ceiling. This type of construction is not used for exterior curtain walls nor for bearing partitions.

Corrugated Siding. Corrugated steel is extensively used for the side walls and roofs of steel mill buildings. Corrugated zinc, asbestos board, and glass are used to a limited extent. All these materials are

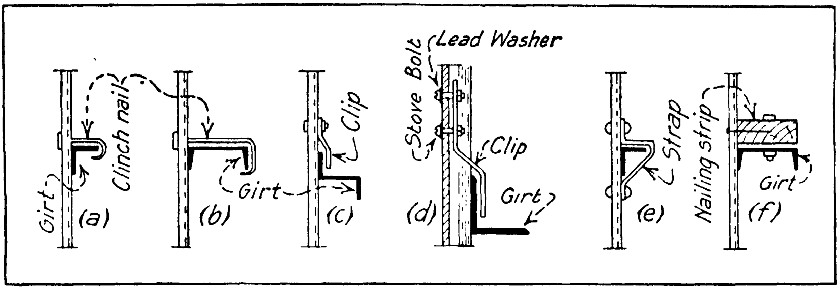


FIG. 179. Fastening Corrugated Siding to Steel Girds

described in Art. 70. The methods used in fastening corrugated steel and zinc to steel girts to form the side walls of mill buildings are illustrated in Fig. 179. In Fig. 179*a* and *b* nails are driven through the tops of the corrugations and clinched around the angle or channel girt. In Fig. 179*c* and *d* a metal clip is bolted to the siding and catches over the girt, the detail shown in 179*d* being used for corrugated asbestos board also. In Fig. 179*e* a metal strap passes around the girt and is fastened to the siding at points above and below the girt. In Fig. 179*f* the siding is nailed to a nailing strip bolted to the back of a channel girt.

This type of construction is inexpensive; but buildings covered with corrugated metal are difficult to heat in winter and they are hot in summer and are unattractive. Condensation on the cold surface of the metal may cause trouble, and if it does anti-condensation lining, as described in Art. 70, may be used. Asbestos-protected metal, in corrugated sheets, is superior to ordinary corrugated steel, so far as insulating properties and weather resistance are concerned, but is much more expensive. It is described in Art. 70.

REFERENCES

1. American Institute of Steel Construction: "Steel Construction," 3rd Ed., 1939.

2. DENCER, F. W.: "Detailing and Fabricating Structural Steel," McGraw-Hill Book Co., 1930.

3. American Welding Society: "Welding Handbook," 1938.

4. Lincoln Electric Co.: "Procedure Handbook of Arc Welding Design and Practice," 1940.

5. OWENS, JAMES W.: Fundamentals of Arc Welding, "Welding Handbook," American Welding Society, 1938.

6. CRITCHETT, J. H.: Fundamentals of Gas Welding, "Welding Handbook," American Welding Society, 1938.

7. WOOFTER, H. A.: Fundamentals of Spot Welding, "Welding Handbook," American Welding Society, 1938.

8. SHEDD, THOMAS CLARK: "Structural Design in Steel," John Wiley & Sons, 1934.

9. American Institute of Steel Construction: "Recommended Fundamental Principles, Tentative Minimum Requirements and Tentative Standard Welded Connections for Tier Buildings," 1939.

10. HALE, ROBERT S.: "Welded Steel Construction," Pitman Publishing Corp., 1938.

11. BURT, HENRY JACKSON, and C. H. SANDBERG: "Steel Construction," American Technical Society, 1939.

12. HAUF, HAROLD DANA: "Design of Steel Buildings," 2nd Ed., John Wiley & Sons, 1938.

13. KETCHUM, M. S.: "The Design of Steel Mill Buildings," 5th Ed., McGraw-Hill Book Co., 1932.

CHAPTER VIII

REINFORCED-CONCRETE CONSTRUCTION

ARTICLE 50. REINFORCED-CONCRETE COLUMNS

Types of Columns. Columns constructed of concrete without reinforcing would be very unreliable and would be cracked easily by bending stresses due to differential settlement, temperature changes, unbalanced loads, or the surrounding floors, etc. Consequently they are not used except where the least width is large in comparison with the length, in which case they would be classed as *piers* rather than as columns. Longitudinal bars are placed near the outside surface of concrete columns to provide resistance to bending but, since the principal load on columns causes compressive stresses, the longitudinal bars if used alone would tend to kick out or buckle and spall off the surrounding concrete. To avoid this, circumferential or lateral reinforcement is used in the form of *ties* spaced 8 to 12 in. apart, as shown in Fig. 180*a*, or in the form of closely spaced hoops.

Because of the difficulty of making individual hoops, a single rod is bent into the form of a helix, as shown in Fig. 180*b*, and acts in the same manner as individual hoops. This is called a *spiral hoop* or simply a *spiral*, although it is really a helix. Columns with ties are called *tied columns*, and those with spiral hoops although usually called *spirally reinforced columns* sometimes are referred to as *hooped columns*. The spiral reinforcement serves another purpose besides that mentioned. By confining the concrete core within the spiral, it prevents sudden and complete collapse of the column and therefore makes it more dependable. Ties are not as effective as spirals in this respect; so the allowable load on a tied column is taken as 80 per cent of the allowable load on a spirally reinforced column with the same longitudinal reinforcing.

Other types of columns are the *composite column*, which consists of a structural-steel section or a cast-iron column thoroughly encased in concrete reinforced with longitudinal and spiral reinforcement, as shown in Fig. 180*l* and *m*; the *combination column*, consisting of a structural-steel section encased in concrete reinforced by a welded wire mesh extending around the columns and effectively lapped; and the *pipe column*, which consists of a steel pipe filled with concrete.

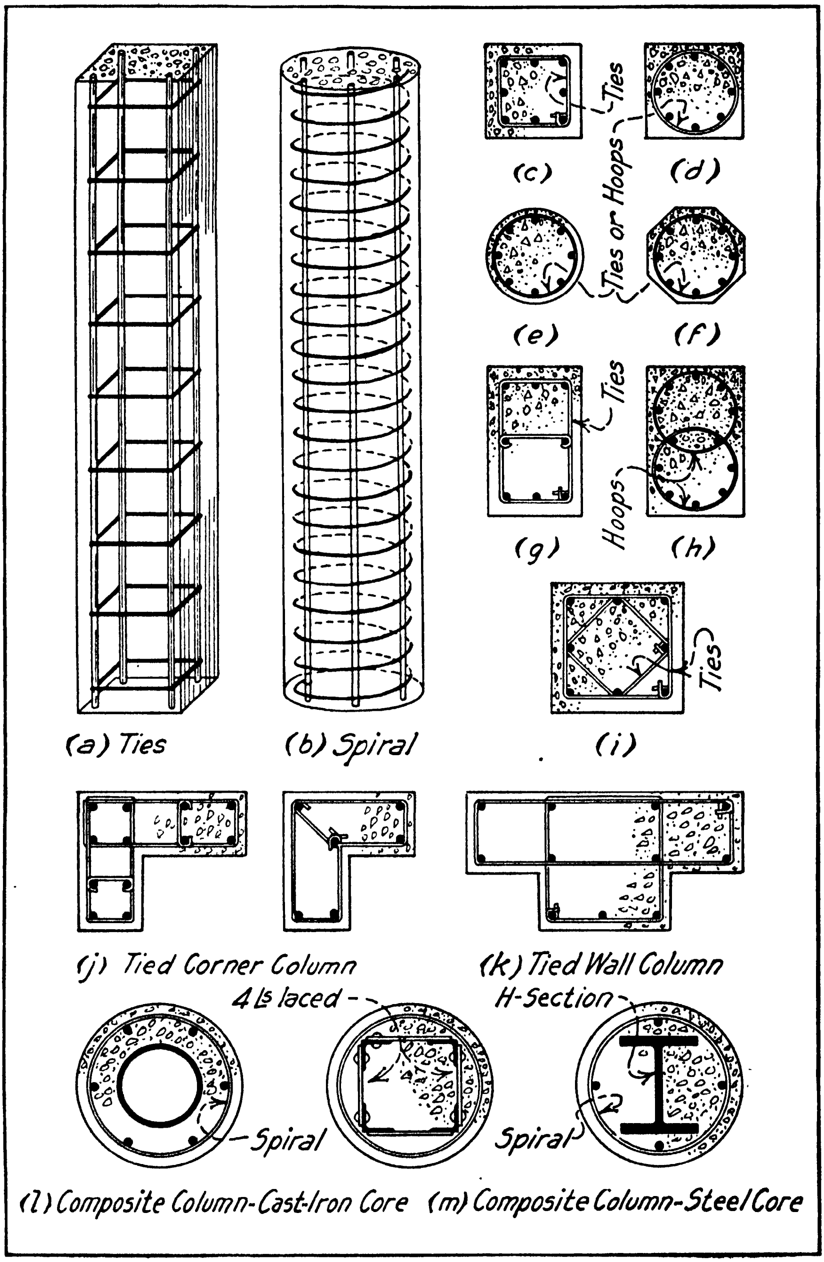


FIG. 180. Reinforced-Concrete Columns

Reinforced-concrete design in this country largely follows the "Recommended Practice and Specifications for Concrete and Reinforced Concrete," prepared by the Joint Committee listed in the references at the end of this chapter. The design requirements included in this chapter are largely based on or quoted from the recommendations made by this Joint Committee in its 1940 Report.[1]

Tied Columns. The load on tied columns is considered as distributed between the concrete and the longitudinal bars. The total area of the longitudinal bars in this type of column should be not less than 1 per cent nor more than 4 per cent of the gross area of the entire column section. There should be at least four bars with a minimum diameter of $\frac{5}{8}$ in. placed with a clear distance from the column face of not less than $1\frac{1}{2}$ in. plus the thickness of the tie. When nearer a corner than 4 in., this covering should be increased to 2 in.

Lateral ties should be at least $\frac{1}{4}$ in. in diameter and should be spaced not farther apart than 16 times the diameter of the longitudinal bars, 48 times the diameter of the tie, or the least dimension of the column. When there are more than four longitudinal bars, additional ties, as shown in Fig. 180*i*, should be provided so that every longitudinal bar is held firmly in place. Tied columns may be made in a great variety of forms, as shown in Fig. 180, to suit special conditions such as those which may exist at wall columns or in the corners. In any case, the ties must be so arranged that each bar is held in position and does not tend to kick out. Instead of using undivided ties, widely spaced spirals, satisfying the specification for ties, may be used.

Spirally Reinforced Columns. The load on a spirally reinforced column is considered as distributed between the concrete and the longitudinal bars. The total area of longitudinal bars in this type of column should be not less than 1 per cent nor more than 8 per cent of the gross area of the entire column section. There should be at least six bars with a minimum diameter of $\frac{5}{8}$ in. The center-to-center spacing of the longitudinal bars within the periphery of the column core should be not less than $2\frac{1}{2}$ times the diameter of round bars nor 2 times the side dimension of square bars. The clear spacing between individual bars or between pairs of bars at lapped splices should be not less than $1\frac{1}{2}$ in., or $1\frac{1}{2}$ times the maximum size of the coarse aggregate.

Spiral reinforcement should consist of evenly spaced continuous spirals held firmly in place by at least three vertical spacer bars. The *core* of a spirally reinforced column is the portion of the column included within a cylindrical surface tangent to the outside of the spirals. For columns whose core diameter is 18 in. or less, the minimum diameter of spiral bars should be $\frac{1}{4}$ in. For larger columns, the minimum diam-

eter of the spiral bars should be $\frac{3}{8}$ in. The center-to-center spacing of spirals should not exceed $\frac{1}{6}$ core diameter. The clear spacing between spirals should not exceed 3 in. nor be less than $1\frac{3}{8}$ in. or $1\frac{1}{2}$ times the maximum size of the aggregate. The column reinforcement should be protected everywhere by a covering of concrete cast at the same time as the core. Its thickness should be at least $1\frac{1}{2}$ in. and not less than $1\frac{1}{2}$ times the maximum size of the coarse aggregate. The Joint Committee Recommendations include a formula which makes the required amount of spiral reinforcement vary with the ratio of the gross area of the column to the area of the core. For this reason, and also to increase the effectiveness of the column in resisting bending stresses, it is desirable to place the spiral and the longitudinal rods as close to the outside of the columns as possible and still secure adequate fireproofing and protection from corrosion.

For columns built monolithically with concrete walls or piers, the outer boundaries of the column section should be considered a circle $1\frac{1}{2}$ in. outside the column spiral or should be considered a square, the sides of which are $1\frac{1}{2}$ in. outside the spiral. In case two or more spirals are used in such a column, as shown in Fig. 180*h*, the outer boundary would be a rectangle, the sides of which are at least $1\frac{1}{2}$ in. outside the spirals. By using more than one spiral, spirally reinforced columns can be made with various forms of cross-sections corresponding to those shown for tied columns in Fig. 180. It is desirable to tie the section together by overlapping the spirals as shown in Fig. 180*h*.

Composite Columns. The structural-steel or cast-iron core of composite columns should be thoroughly encased in reinforced concrete consisting of both longitudinal and spiral reinforcement, meeting the requirements which have been given for spirally reinforced columns. The load is considered carried by the concrete, the longitudinal bars, and the core. The cross-sectional area of the core should not exceed 20 per cent of the gross area of the column. If a hollow core is used, it should be filled with concrete. There should be a clearance of at least 3 in. between the spiral and the core, except when an H section is used as a core the minimum clearance can be reduced to 2 in. The metal cores should be accurately milled to secure good bearing at the splices and provision must be made, by brackets or other connections, to transfer loads to the metal core.

Combination Columns. In a combination column consisting of a structural-steel section encased in a concrete core, all the load is considered carried by the structural steel, with its carrying capacity increased by the stiffening effect of the concrete casing. No load is considered carried by the concrete. The concrete is held in place and

reinforced by welded mesh with wires at least $\frac{1}{8}$ in. in diameter, spaced not farther apart than 4 in. vertically and 8 in. horizontally. This mesh should extend entirely around the columns at a distance of 1 in. inside the outer concrete surface and should be lapped at least 40 wire diameters and wired at the splice. Special brackets should be provided on the structural-steel section to receive the entire load at each floor level.

Pipe Columns. The load on pipe columns is considered distributed between the steel pipe and the concrete with which it is filled. Pipe columns are used to a limited extent in relatively low non-fireproof buildings. If used in a fireproof building, they should be protected in the same way as other metal columns.

ARTICLE 51. REINFORCED-CONCRETE BEAMS AND GIRDERS

Concrete is strong in compression but weak in tension. If steel rods are placed in the concrete on the tensile side of a beam as shown in Fig. 181*a*, these rods will carry the tensile stresses and a very efficient form of beam will result. A sufficient amount of steel reinforcement is usually used to make the beam as strong in tension as it is in compression.

The simplest form of beam is rectangular in section, as shown in Fig. 181*b*; but, since the concrete on the tensile side of the beam is not considered as carrying any stress, some of this concrete may be left out of wide beams, leaving only enough to carry the steel rods and to provide for the shearing stresses. This forms the T beam shown in Fig. 181*c*. The outline of the corresponding rectangular beam is shown by the dotted lines. Usually some of the concrete on the compressive side near the neutral axis is also omitted, as shown in Fig. 181*d*. By referring to Fig. 93*e*, it may be seen that the stress carried by this material is small so that the strength of the beam is reduced only slightly by this omission.

In some cases, the size of a beam is limited and it is necessary to design a beam of given strength to fit into a space which is smaller than would be required for an ordinary rectangular or T beam. The tensile strength may be secured by providing the required amount of tensile reinforcement, but the amount of concrete which is available for compression is limited by the space to be occupied. In this case, the additional compressive strength necessary is secured by placing steel bars on the compression side of the beam, forming a double-reinforced rectangular beam as shown in Fig. 181*e*. A given amount of steel is about 15 times as effective in compression as the same amount of con-

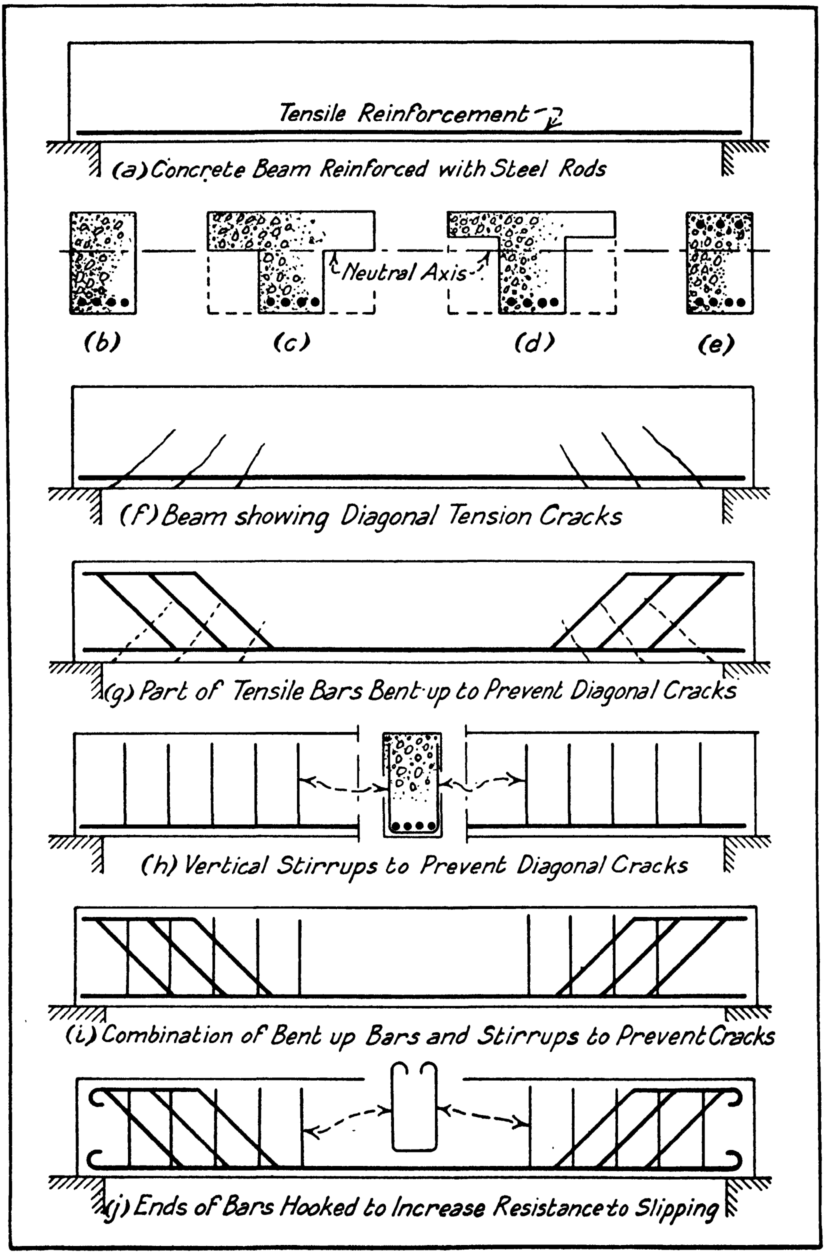


FIG. 181. Simple Reinforced-Concrete Beams

crete; however, it is more economical to use concrete to carry compressive stresses than it is to use steel.

So far only tensile and compressive stresses have been considered, but it is necessary to provide for shearing stresses also. These stresses combined with the tensile stresses cause diagonal tension stresses which tend to cause diagonal cracks near the ends of a beam, as shown in Fig. 181*f*. Where these stresses are large, it is necessary to provide reinforcement to prevent these cracks. This reinforcement may be provided by bending up a part of the tensile reinforcement, as shown in Fig. 181*g*, or by providing vertical U-shaped members passing around the tensile steel, as shown in Fig. 181*h*. These members are called *stirrups* and should not be spaced farther apart than one-half the depth of the beam. Various other forms of stirrups may be used. In rectangular beams reinforced for compression, stirrups have the additional function of holding the compressive steel in position and overcoming the tendency of these bars to kick out. Here the stirrups have an action similar to the ties or hoops in columns. Usually a combination of bent-up bars and stirrups is used, as shown in Fig. 181*i*. The ends of stirrups should be hooked to increase their resistance to slipping. In beams reinforced for compression, they are bent around the compressive steel. Steel reinforcement does not prevent the formation of cracks on the tensile side of a beam, but if the steel is not overstressed the cracks are very small and are not objectionable.

Still another form of stress which must be provided for is known as *bond stress*. Bond stresses are caused by the tendency of the steel to slip in the concrete when a beam is loaded. This is frequently a serious matter. To increase the bond strength, deformed bars may be used. The resistance to slipping may be increased by *end anchorage* or by hooking the ends of bars, as shown in Fig. 181*j*.

The reinforcement in continuous beams must be arranged differently from that in simple beams. If reinforcement were provided at the bottom of the beam only it is evident that the beam would crack over the intermediate supports, as shown in Fig. 182*a*, owing to the tensile stresses which exist in the upper part of the beam at those points; and if the ends are constructed monolithic with columns, cracks will develop on top at or near the columns. To prevent these cracks it is necessary to provide steel near the top surface in the parts of the beam near the supports, as shown in Fig. 182*b*. Instead of using separate bars at the top, it is more convenient to bend up some of the bars from the bottom where they are no longer needed, as shown in Fig. 182*c*. At least one-fourth of the bars in the bottom should be left at the bottom. Usually the splices in the bars are made over the supports and the bars will be

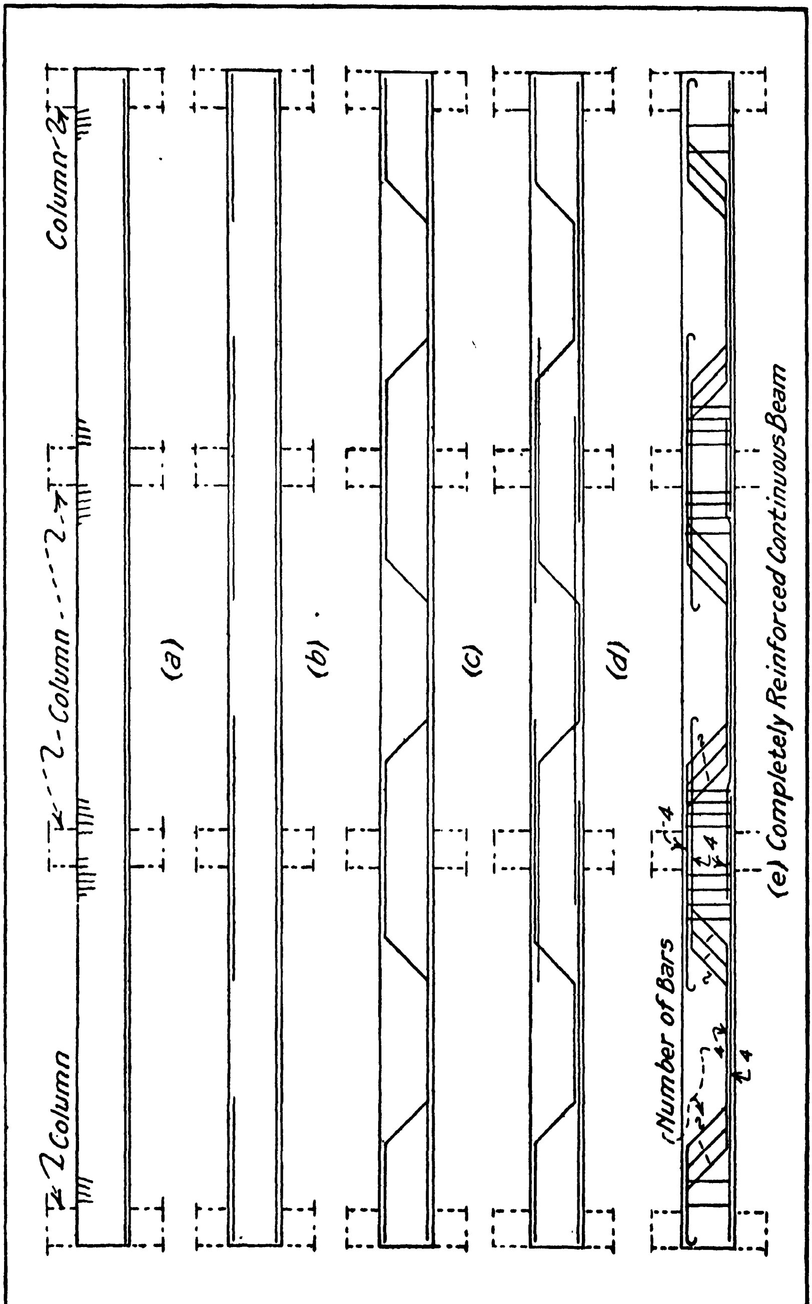


FIG. 182. Continuous Reinforced-Concrete Beams

arranged as shown in Fig. 182*d*, but not necessarily separated vertically as shown in the figure for the sake of clearness. The ends of the tensile bars are commonly hooked to increase their resistance to slipping. The inclined portions of the bent-up bars are effective in resisting diagonal tension stresses and are utilized for that purpose but it is usually necessary to use stirrups to take care of the parts of the beam where shear reinforcement is necessary that are not provided for by bent-up bars. It is desirable to bend up bars at more than one point at each end of each beam as shown in Fig. 182*e*. This figure illustrates a completely reinforced-concrete beam built monolithic with the supporting columns. The columns must be reinforced to resist any bending stresses introduced by the beams or from other causes.

In building construction, floor slabs are commonly cast monolithic with the beams and girders, as shown in Fig. 183*c*. This slab is effective in carrying compressive flexural stresses when such stresses occur in the upper part of the beam but near the supports the compressive stresses are in the lower part of the beam so that the floor slab is not effective in this capacity. At these points the bars which run straight through near the bottom of the beam are utilized to carry a part of the compressive stresses. Continuous beams which are cast monolithic with the floor slabs are therefore T beams in the central part of the span and double-reinforced rectangular beams over the supports. See Art. 52 for further discussion.

ARTICLE 52. REINFORCED-CONCRETE SLABS

Ordinary Slabs. Reinforced-concrete slabs may be considered wide shallow beams. They are used as floors and roofs of buildings with masonry-bearing walls or with reinforced-concrete or steel frames. In some cases, they are supported by timber beams but this type of construction is not desirable.

The simplest case is that of separate slabs supported on steel beams, as shown in Fig. 183*a*, but this type of construction is not common. Usually the slabs are continuous over the beams, as shown in Fig. 183*b*. Here it is necessary to provide steel near the top of the slabs over the beams because the tensile stresses are on that side at this point. This may be provided by bending up some of the steel from the bottom of the slab or by short bars over the supports. Although no tensile stresses exist at the bottom of the slab over the supports, it is desirable to run at least one-fourth of the bottom steel straight through. The amount of steel required at the top of the slab over the beams is usually about equal to the amount required at the bottom in the center of the span. In buildings which are classed as fireproof it is necessary to protect

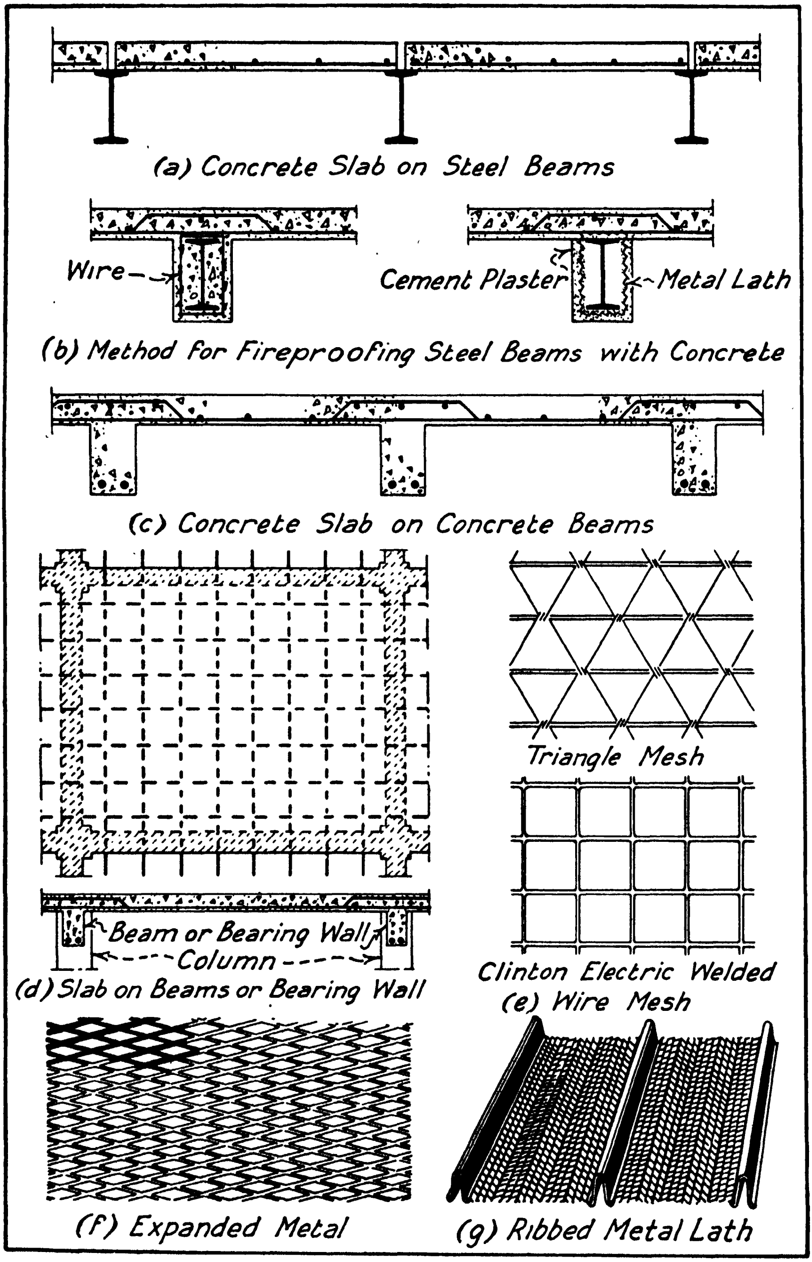


FIG. 183. Reinforced-Concrete Slabs

the steel beams by surrounding them with concrete, as shown in Fig. 183*b*. Less effective protection is provided by metal lath and plaster.

Reinforced-concrete slabs are commonly constructed monolithic with reinforced-concrete beams and girders, as shown in Fig. 183*c*. In this case, the slab serves the double function of spanning the space between the beams and acting as the flange of the T beams which support it. The slabs are continuous over the beams and require tensile steel near the top over the beams. Specifications commonly permit the portion of

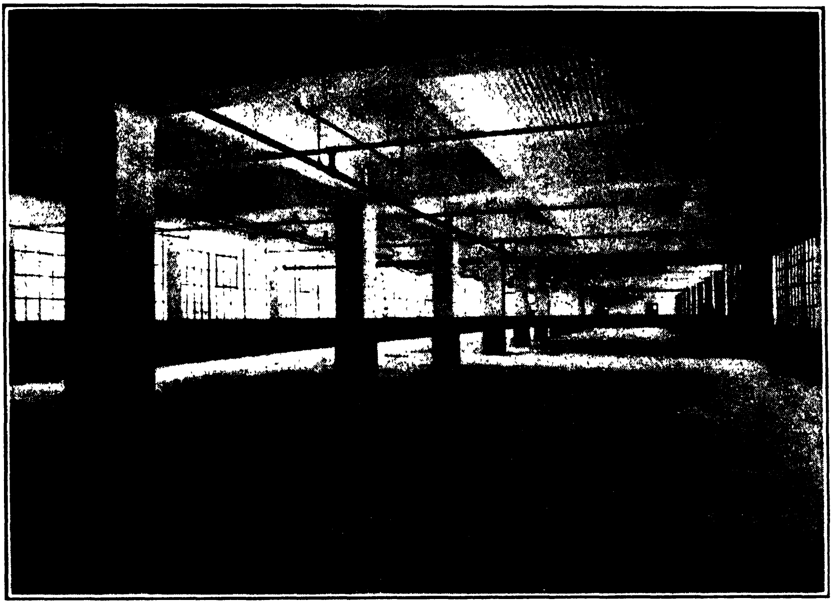


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FIG. 184. Reinforced-Concrete Beam and Girder Construction

the slab extending 8 times its thickness each side of the beam to be considered as the flange of the T beam. However, the total width of the slab so considered can not be greater than the distance center to center of beams or greater than one-fourth the span of the beams. It is sometimes possible and desirable to support a slab on four sides by means of beams or bearing walls, as shown in Fig. 183*d*. An interior view of a building with monolithic beams, girders, and slabs is shown in Fig. 184.

The principal reinforcement for slabs will, of course, run perpendicular to the supporting members, but it is necessary to provide a small amount of reinforcement parallel to the supports to prevent cracks due

to temperature changes and to assist in the lateral distribution of concentrated loads. The reinforcement usually consists of round or square bars, but light slabs may be reinforced with some form of wire mesh, as shown in Fig. 183*e*, or expanded metal lath, as shown in Fig. 183*f*. The ribbed metal lath shown in Fig. 183*g* is used on light slabs poured without the usual forms, the ribs being sufficiently rigid to span the distance between supports and the mesh being so fine that the concrete will not run through but is able to form a substantial grip on the mesh. A slab of this type supported on open-web steel joists is illustrated in

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FIG. 185. Reinforced-Concrete Flat-Slab Construction

Fig. 202. The rough lower side of the slab is concealed and protected from fire by the plastered ceiling supported on the under side of the joists. Other forms of steel joists described in Art. 45 are used in the same manner as the pressed steel joists shown in the figure. The spacing of the joists of the various types varies from 12 to 30 in. The thickness of the slab varies from 2 to 3 in. Some codes place a minimum thickness of 2½ in. on all concrete slabs.

Flat Slabs. In the slab reinforced in both directions illustrated in Fig. 183*d*, the beams running between columns on the four sides of each panel are deeper than the slab and project below the slab. By making

these beams very wide, it is possible to make them the same depth as the slab and thus obtain a flat ceiling. To carry these wide beams it is necessary to flare the columns out at the top, forming what are called *capitals,* and to further assist in carrying the load, *drop panels* are used. This type of construction is illustrated in Fig. 186*a,* and is called the *two-way-system flat slab,* because the reinforcement runs in two directions. The width of the beams is usually considered half the width of the panel, the remaining area acting as a slab supported on four sides.

In the *four-way system,* an extra set of wide flat beams is run diagonally between the columns as illustrated in Fig. 186*b*. In this system the reinforcement runs in four directions.

In both systems most of the reinforcement is near the bottom of the slab in the central part of each beam, and near the top where it passes over the drop panel and column capital. It is necessary to provide reinforcement in the top of the slab in other parts of the slab where cracks tend to form on top.

There are many other flat-slab systems, but those just described will serve to illustrate this general type of construction. An interior view of a building of flat-slab construction is shown in Fig. 185.

Flat-slab construction is advantageous for buildings in which the panels are approximately square, where the floors are heavily loaded, where exposed beams and girders interfere with the headroom, or where it is desirable to place the tops of windows as near the ceiling as possible to secure better lighting in the building. This type of construction is particularly desirable for factories, warehouses, and other industrial buildings, but is not economical for office buildings and apartment houses where the loads are light, and is not desirable for these buildings on account of the interference of the column capitals with the partitions. Steel forms which may be rented are usually used for the columns, and steel forms may be used for the slabs. It is evident that the formwork for the slabs is very simple.

Ribbed Slabs. In reinforced-concrete beams and slabs the concrete between the neutral axis and the tension face is not contributing to the flexural strength, but is effective in resisting a part of the shearing stresses as explained in Art. 51. The shearing stresses in slabs are usually low, and so this concrete is not necessary. In order to save concrete and to reduce the weight of the slab, a large part of the concrete on the lower side of the slab is eliminated, leaving only the ribs or joists, as shown in Fig. 187*a,* the bottom of the corresponding solid slab being at the bottom of the ribs. These ribs are made wide enough to resist the shearing stresses and to carry the necessary tensile steel which is practically the same amount as required for the solid slab, except for

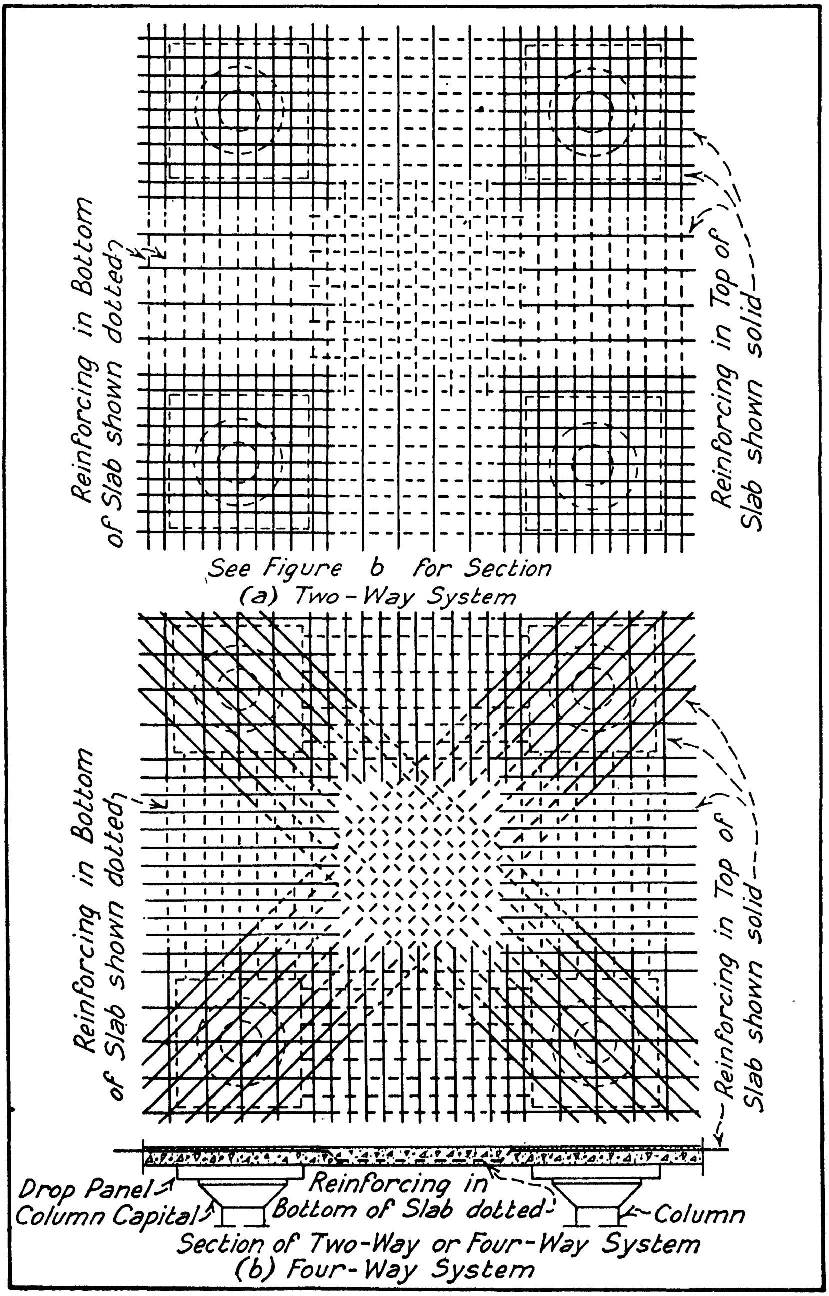

FIG. 186. Flat Slabs of Reinforced Concrete

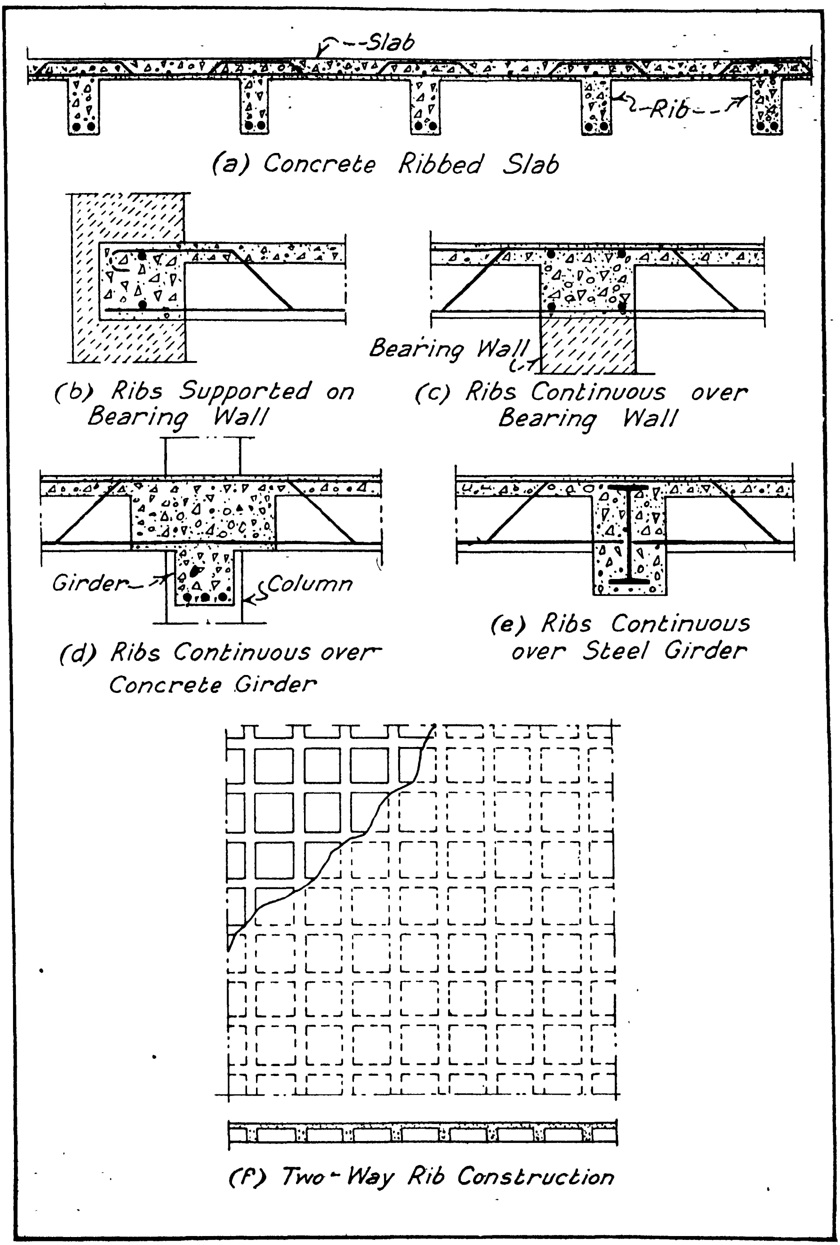

Fig. 187. Ribbed Slabs of Reinforced Concrete

the saving in steel due to the reduction of the dead load. The remaining flange may extend down to the neutral axis but usually it does not. This results in a reduction in the compressive resistance, but this is small because the concrete near the neutral axis carries very little stress. This may be seen by consulting Fig. 93*e*. The solid slab would be reinforced with relatively small bars closely spaced, but in the ribbed slab two large bars are commonly used in each joist. This results in increased bond stresses, but such stresses are not often a controlling factor. Some codes require solid bridging, spaced not more than 8 ft. apart, for joist floors. See Fig. 189. This bridging is commonly 4 in. wide and the full depth of the joists. It is reinforced with one rod near the top and one near the bottom. The function of such bridging is primarily to distribute heavy loads such as those due to partitions, safes, bookcases, etc., over several joists. The minimum width of joists is 4 in., and the depth below the bottom of the slab is sometimes limited to three times the width. The slab between the ribs or joists varies from 2 to 4 in. in thickness and is reinforced with a wire mesh or with $\frac{1}{4}$-in. or $\frac{3}{8}$-in. bars about 12 in. apart, running perpendicular to the joists, and with other small bars about 18 in. apart parallel with the joists. The bars are not bent up over the joists. Ribbed slabs are extensively used in fireproof buildings for spans from 10 to 35 ft.

The detail used where the end of a ribbed slab is supported by a bearing wall is shown in Fig. 187*b*. The details used for slabs continuous over bearing walls, concrete girders, and steel girders are shown in Fig. 187*c* to *e*. The reinforcing in the slab is not shown in these figures but is the same as shown in Fig. 187*a*.

Occasionally it may be advantageous to support a slab on four sides and provide ribs in two directions as shown in Fig. 187*f*.

Ordinary wood forms would be so expensive for ribbed slabs that their cost would be prohibitive. For this reason various types of construction have been devised to take the place of such forms. The sides of the joists and the bottom of the slab are formed by hollow-clay tile, hollow-gypsum tile, or sheet-steel cores as shown in Fig. 188*a* to *c*. Wood forms are constructed for the bottoms of the joists. These are usually made of 2-in. material and are sufficiently wider than the joists to support the edges of the clay or gypsum tiles or the steel pans. The formwork is therefore very simple.

The clay tiles and the gypsum tiles provide a surface which serves as a plaster base for the ceiling formed by the under side of the slab. The ends of the end tiles may be closed by a thin slab made for that purpose, by using pieces of wire screen or in some other way, or they may be left open, in which case concrete will run a short distance into the cells.

The sheet-steel cores may be made of heavy material which will stand being removed after the concrete has set and being used several times. They may also be made of thinner material designed to be left in place. If the removable forms are used, metal lath is fastened to the under side of the joists to serve as a base for plaster for the ceiling below. Various types of anchors are available for casting in the under side of the joists to receive the metal lath. If the sheet-steel cores are to be left in place, metal lath is laid over the forms before the cores are set. The metal lath is wired to the reinforcing bars in the joists. In one type of steel core, the lath is fastened to the core as shown in Fig. 188*d* before the core is placed. Sheet-metal closers or end caps are made for the ends of the end cores. It is sometimes necessary to widen the joists at the ends on account of excessive shearing stresses. This is accomplished by using tapered cores at the ends of the joists. The most common width of core is 20 in. which, with a joist 4 in. wide, gives a 24-in. joist spacing. The depths available vary from 6 in. to 14 in. by 2-in. increments. They are usually corrugated to increase their stiffness and are lapped one or one-half corrugations or more if necessary to provide the exact lengths required. The cores are supported on forms placed under the joists. No forms are necessary between the joists. Removable cores may be used several times but to stand moving they must be constructed of heavier metal than the cores which are left in place, the cost of removing must be considered and also the greater cost of placing the lath. The type most suitable for a given case can only be determined by studying all of the factors involved. An interior view showing a ribbed-slab floor constructed with removable sheet-steel cores is given in Fig. 189. Bridging is used in the middle of the span.

Special types of tile and sheet-steel cores are available for the two-way type of construction. A steel core for two-way construction is shown in Fig. 188*e*.

A form of flat-slab construction has been devised to make use of the ribbed slab in place of the flat slab. This is known as the *grid flat slab* and is illustrated in Fig. 188*f*. The reinforcing is not shown in this figure, but would be similar to that used in the two-way system shown in Fig. 186*a*.

ARTICLE 53. REINFORCED-CONCRETE ARCHES AND RIGID FRAMES

The use of reinforced-concrete arches and rigid frames in building construction is increasing very rapidly. The most extensive use is in roof construction. A simple type of roof construction is illustrated in Fig. 190*a*. The roof consists of slabs running between beams or

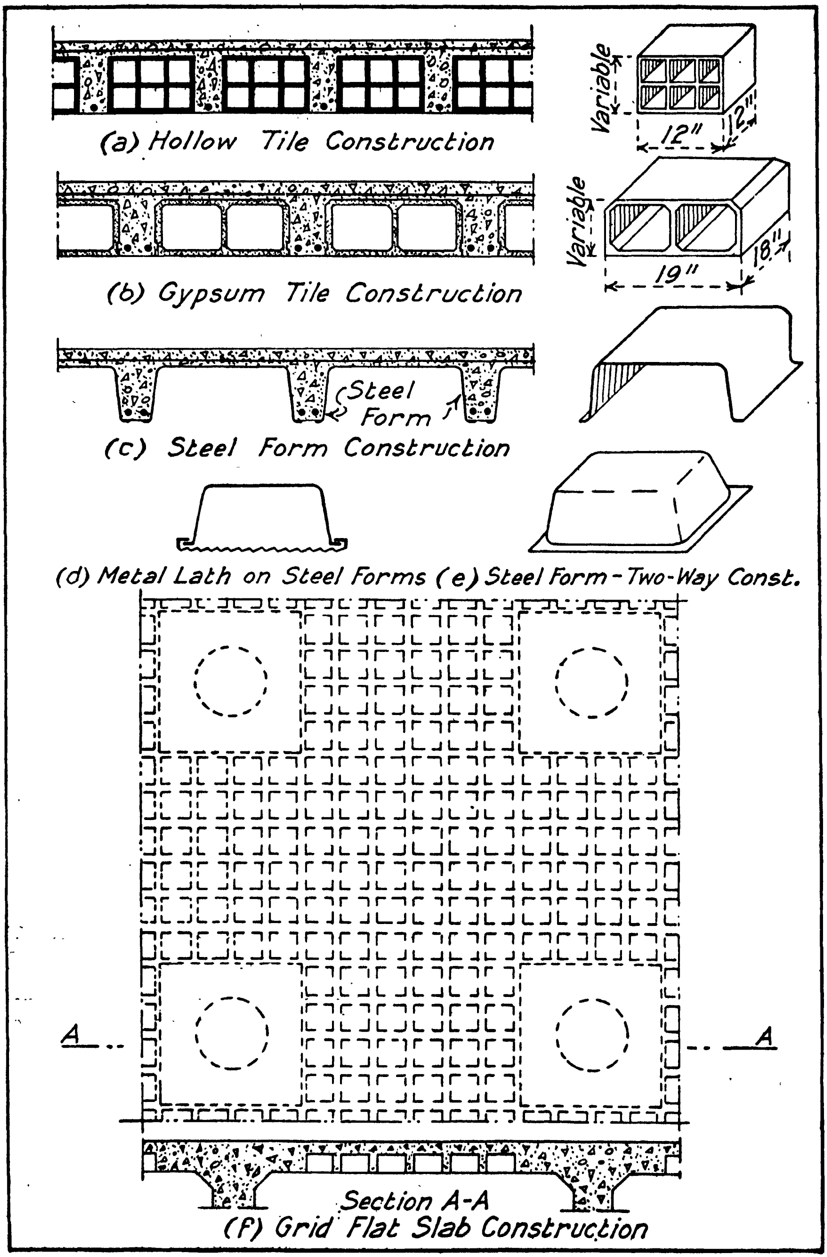

FIG. 188. Cores for Ribbed Slabs and Grid-Flat-Slab Construction

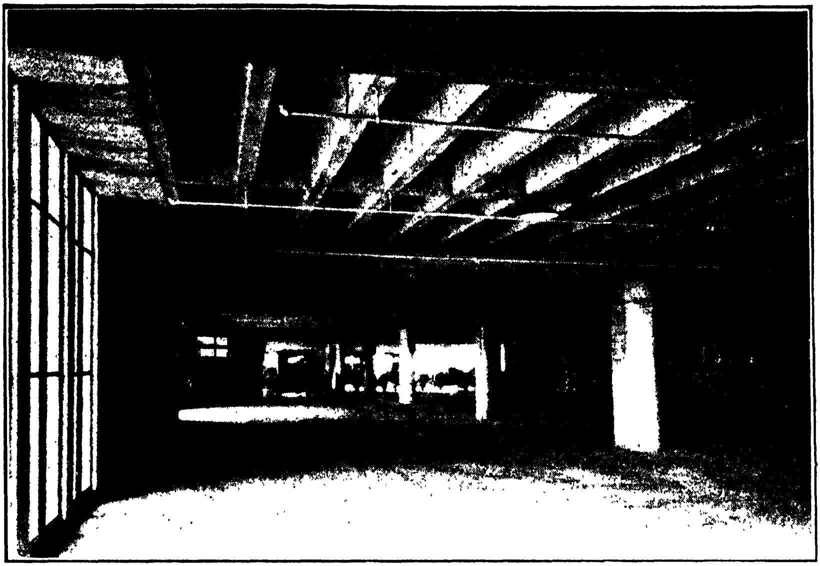

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FIG. 189. Reinforced-Concrete Ribbed-Slab Construction

purlins which are supported on reinforced-concrete arches spaced 12 to 25 ft. or more apart. The horizontal reactions of the arches are taken by tie rods running from one side of the building to the other. These tie rods are supported at intervals by sag rods which hold them in a horizontal position. The ties and sag rods are protected by concrete fireproofing. The tie rod may be replaced by a reinforced-concrete tension member made up of several rods which are spliced by lapping a sufficient distance to develop their strength in bond. Arches of this type have been constructed with spans of 100 ft. and over.

Instead of using tie rods, as shown in Fig. 190*a*, the arch may be extended to the ground, as shown in Fig. 190*b*. This permits the tie rods to be concealed in the floor. The bending stresses in the arch ring are greatly increased by using this type of arch, but the structure is much more attractive than that with the exposed tie and the increased stresses are readily taken care of in design. Such a structure should probably be classed as a rigid frame rather than as an arch. Another form of rigid frame which provides a sloping roof instead of a curved roof as in Fig. 190*b* is shown in Fig. 190*c*. Other types of reinforced-concrete rigid frames are shown in Fig. 99. A more detailed drawing of a reinforced-concrete rigid frame is shown in Fig. 191, and interior views of buildings with such frames are shown in Figs. 192 and 193. Rigid

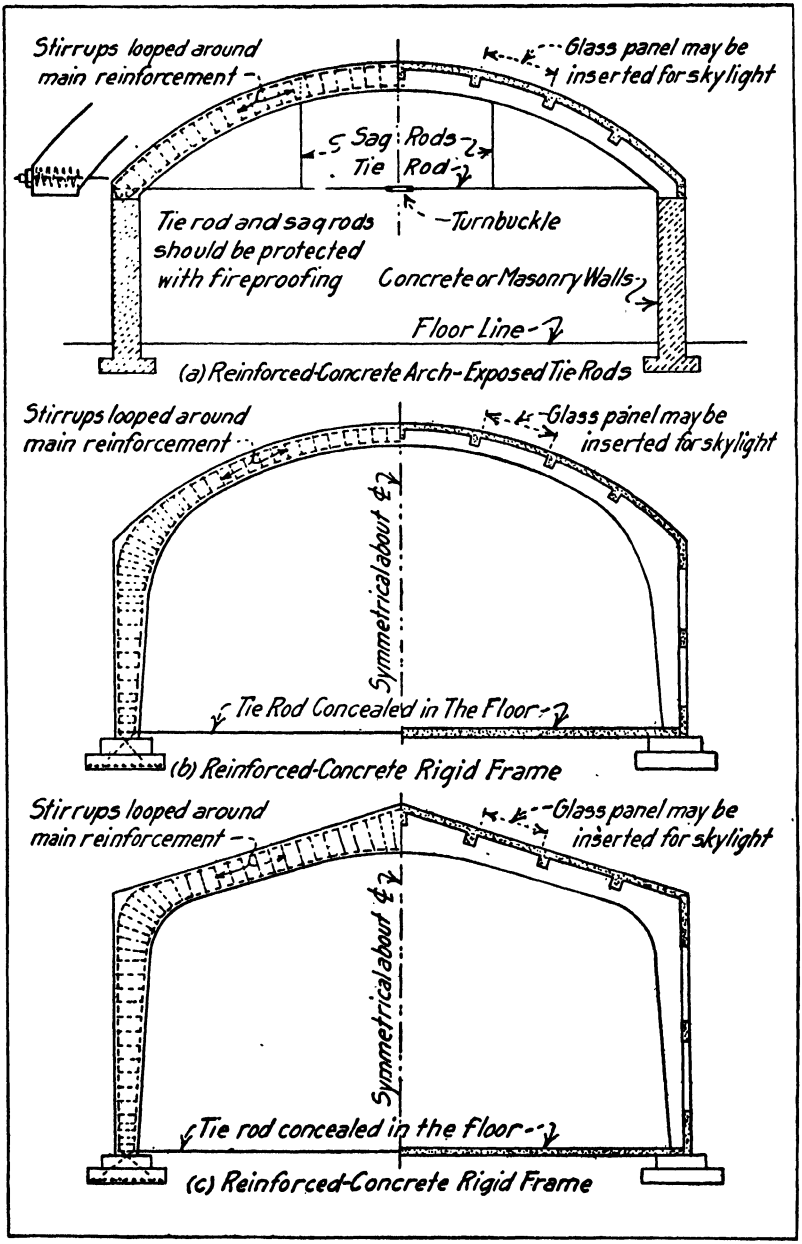

FIG. 190. Simple Reinforced-Concrete Arch and Rigid Frames

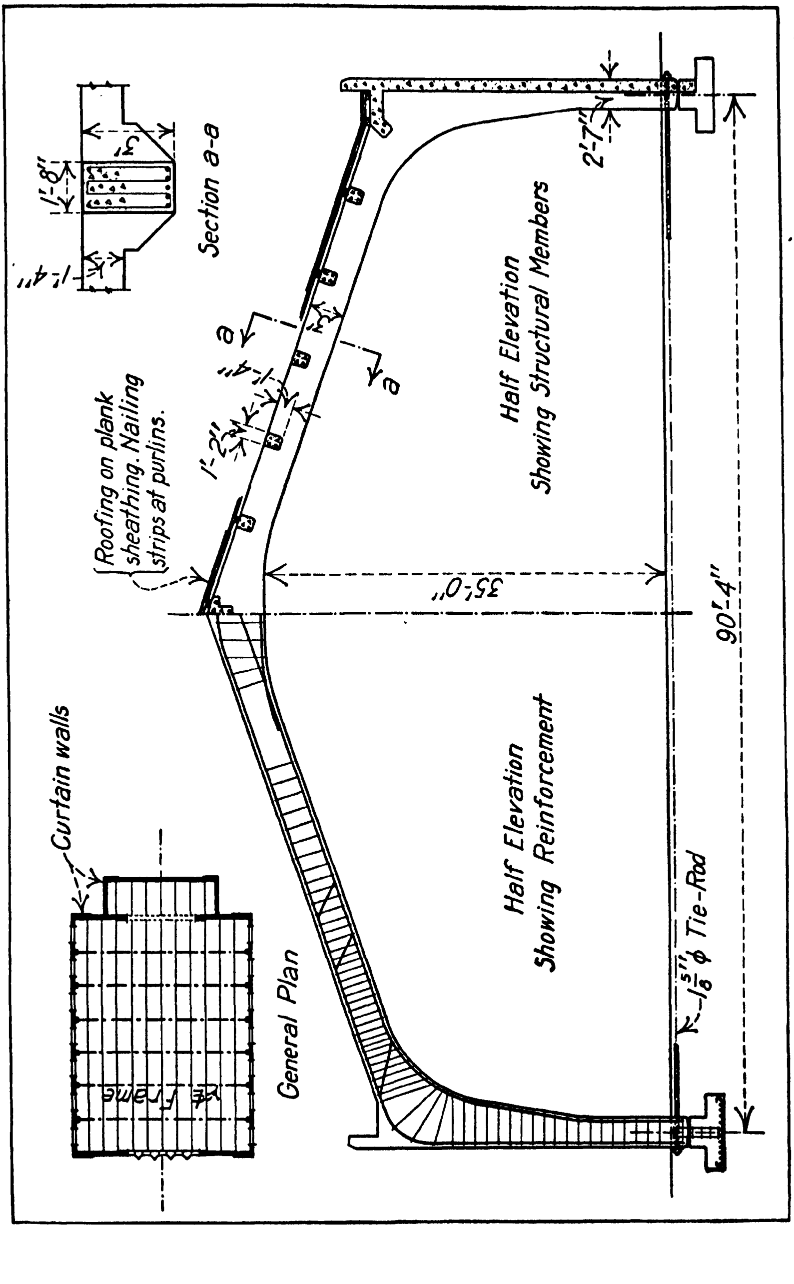

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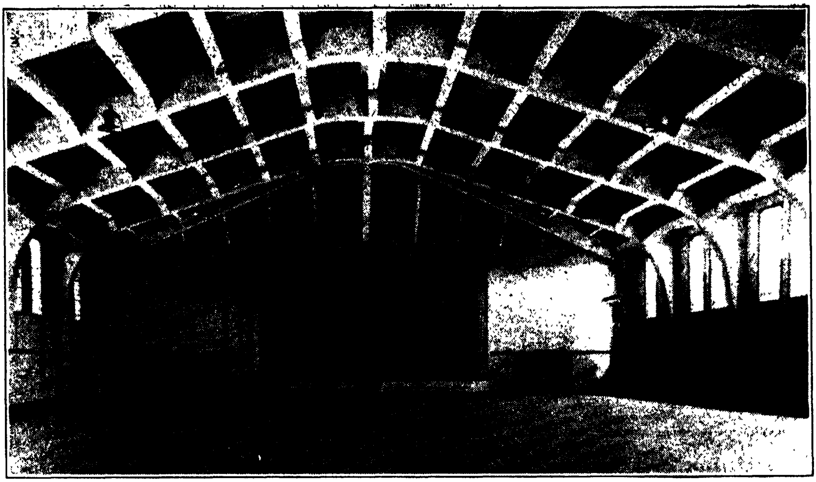
FIG. 191. Reinforced-Concrete Rigid Frame in an Armory



Works Progress Administration of Illinois

FIG. 192. Reinforced-Concrete Rigid Frames

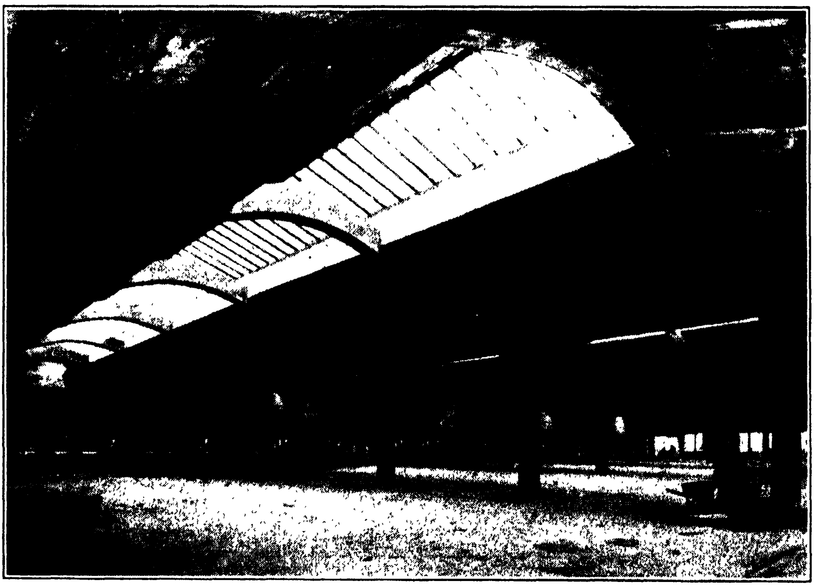


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FIG. 193. Reinforced-Concrete Rigid Frames

frames of reinforced concrete which have been made hollow to decrease their weight have been used for spans up to 150 ft. A shorter span of this type is shown in Fig. 194.[2]

A roof in which the principal structural elements are two-hinged reinforced-concrete arches with a span of 222 ft. center to center of hinges, and spacing of nearly 40 ft., is illustrated in Fig. 195. The shell roof between the arches is only 3½ in. thick, except near the lower edges where it is gradually increased to 6 in. The roof is designed following the Ziess-Dywidag or Z. D. system which differs quite markedly from the usual procedures followed in such cases.[3]

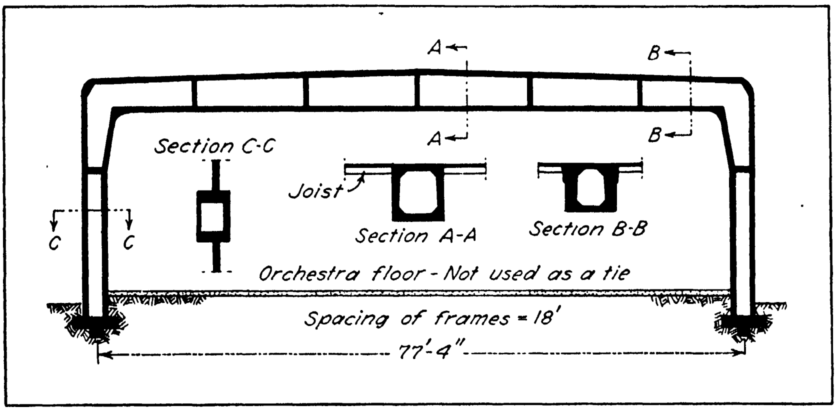

FIG. 194. Hollow Reinforced-Concrete Rigid Frame

ARTICLE 54. REINFORCED-CONCRETE FRAMING

In framing a reinforced-concrete building the forms are first constructed, the reinforcing steel is then placed, and finally the concrete is poured, as described in Art. 10. After the concrete has set, the forms are removed. It is obviously impossible to pour an entire building in one operation, so construction joints can not be avoided. These should be so located and constructed as to impair the strength of the building as little as possible. The joints in slabs, beams, and girders should be vertical and at the center of the span where the shearing stresses are small. The columns should be poured to the under side of the floor girders for beam and girder construction so that the shrinkage which occurs in the concrete of the columns may take place before the floor above is poured.

Forms are usually constructed of wood, but steel forms are quite extensively used especially for buildings of flat-slab construction. The

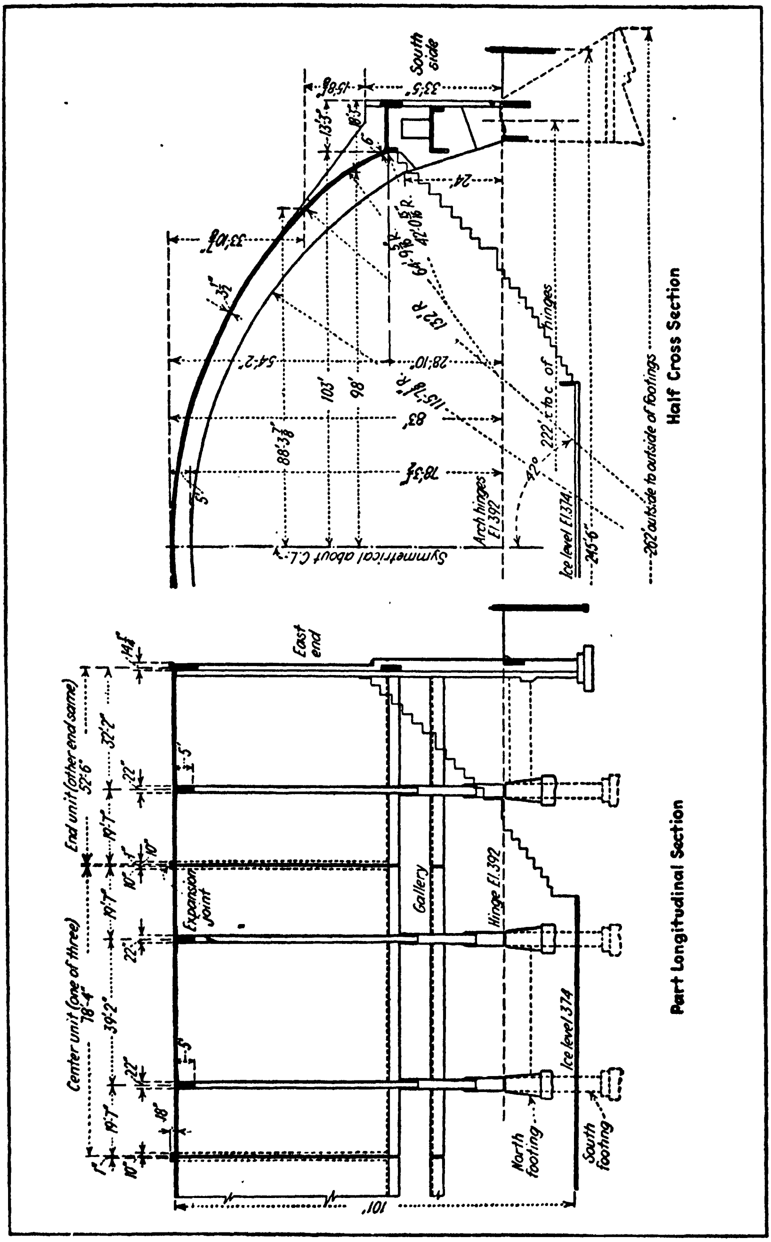

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FIG. 195. Reinforced-Concrete Shell Roof Supported by Two-Hinged Arches

reinforcing steel is held in position by wiring the bars together at their intersections. The bars for each beam, girder, and column are commonly wired together to form a frame which is set in position as a unit. Various devices such as chairs and spacers have been designed to hold reinforcing steel in position.

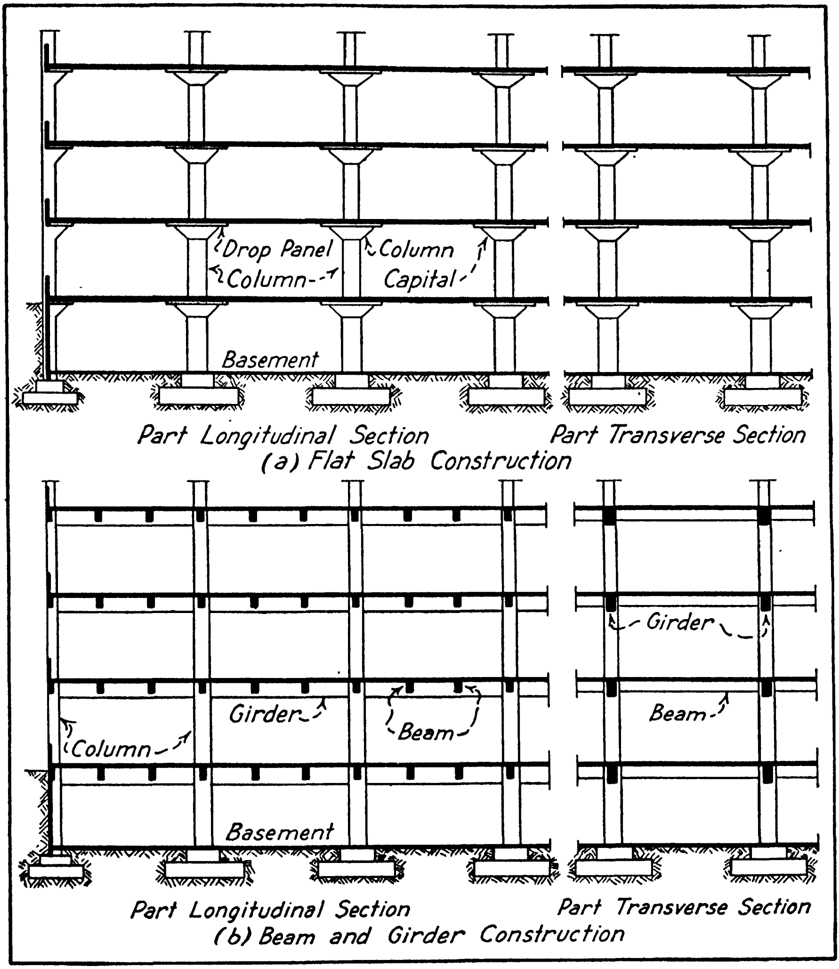

FIG. 196. Types of Reinforced-Concrete Framing

Reinforced-concrete buildings may be of the bearing-wall type of construction or of skeleton construction. The bearing walls may be constructed of brick, stone, hollow tile, or plain concrete or they may be constructed of reinforced concrete, as shown in Fig. 90 and described in

Art. 30. Skeleton construction buildings may be of the beam and girder type, as shown in Fig. 196*b*, or of the flat-slab type, as shown in Fig. 196*a*. A building with reinforced-concrete bearing walls is shown in Fig. 197, and a skeleton frame in Fig. 198.

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Fig. 197. Reinforced-Concrete Bearing-Wall Construction

Typical details for a building of the beam and girder type are shown in Fig. 199. The features which should be noted in this figure are:

1. The reinforcing in the slab. Reinforcing is provided at the bottom of the slab near the center of the span and at the top where the slab crosses the beams. Some of the bottom steel continues through on the bottom.

2. The reinforcing in the beams is not shown but is similar to that in the girders and consists of horizontal bars in the bottom of the girder, and bars bent up from the bottom of the girder at the center to the top in the region near the supporting columns. The ends of the bars are hooked in most cases.

3. Vertical stirrups which are more closely spaced near the ends of the girder where the shearing stresses are high.

4. Spread footings are used. The reinforcing bars in the footings are hooked at the ends. Dowels extend from the footings into the columns. These dowels should be equal in size and in number to the

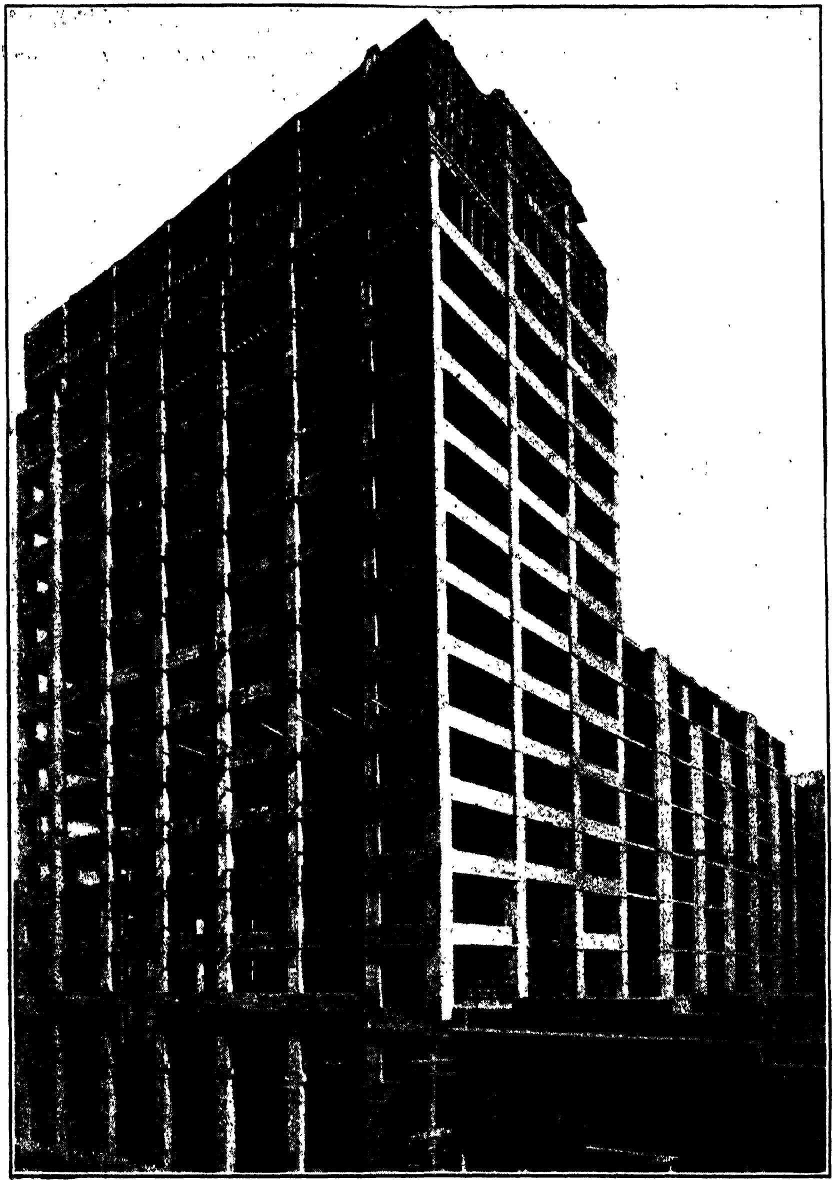

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FIG. 198. Reinforced-Concrete Skeleton Construction

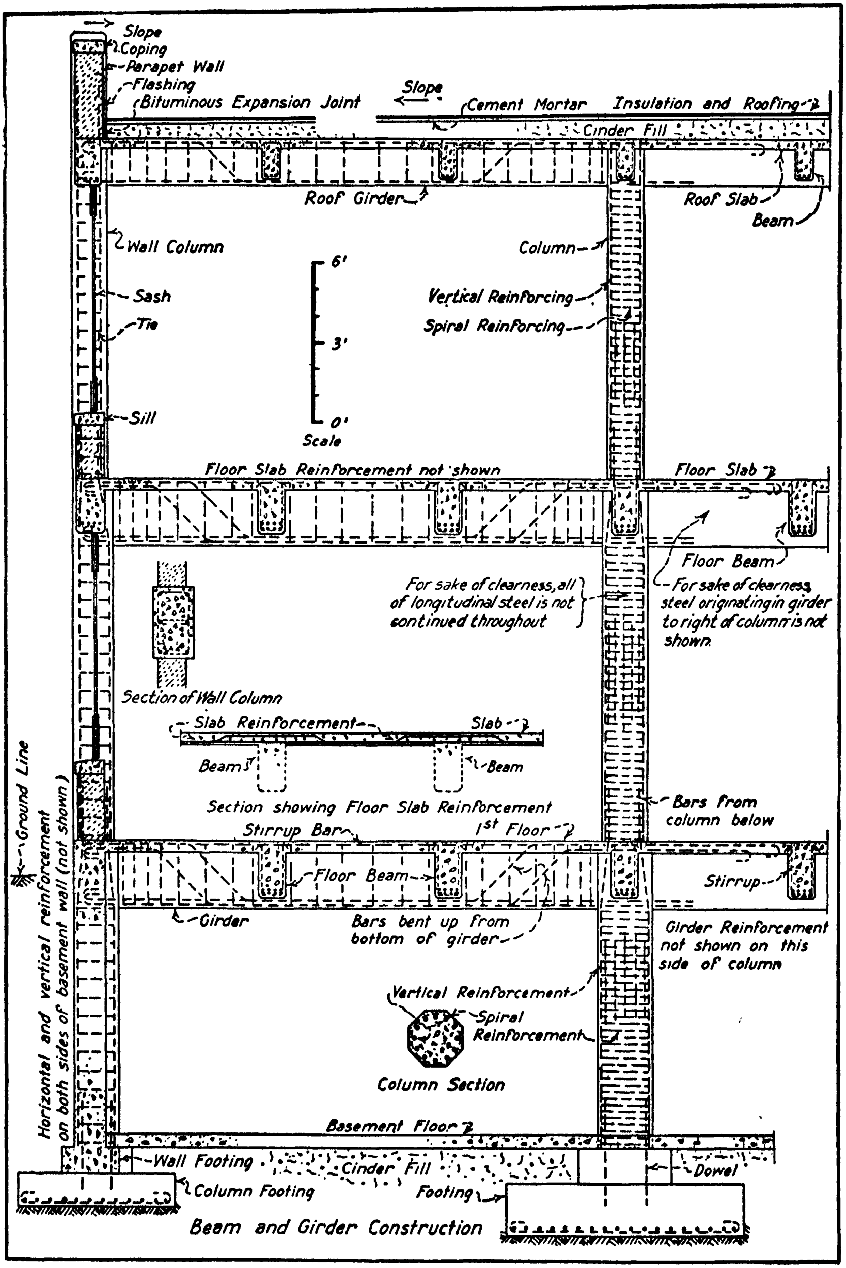


Fig. 199. Reinforced-Concrete Beam and Girder Construction

longitudinal bars in the column as their function is to transfer the stress in the column bars to the footing. They must extend into the column and into the footing a sufficient distance so that their bond stress will not be excessive.

5. The longitudinal bars in the interior columns are arranged around the edge of the columns and are surrounded with closely spaced spiral reinforcing. To avoid confusion all the longitudinal bars are not shown in the elevation but they are shown in the section.

6. The longitudinal bars of the wall columns are held in position by lateral reinforcement in the form of ties which are not as closely spaced as the spirals of the interior columns. Spirally reinforced columns might have been used.

7. The columns are spliced by running the longitudinal bars from one column upward into the column above. To take care of the smaller size of the upper columns the bars are bent inward in the part of the column occupied by the floor construction. They are again made vertical after the floor level is passed.

8. The slope of the roof is obtained by a cinder fill with a cement mortar topping to receive the built-up bituminous roofing. The cinder fill also serves as heat insulation. An expansion joint is provided between the filling and the parapet wall so that the topping can expand as it becomes heated. If this provision were not made the topping would either buckle or push the parapet wall out. Similar expansion joints should be provided at other points in the topping. Some designers object to a cinder fill because, if leaks develop in the roofing, the fill may absorb water and freeze. Under these conditions, the fill may expand and exert a thrust against the parapet walls and cause them to crack. It is usually undesirable to slope the slab for drainage. Good results have been secured with decks which do not slope to drains, because any shallow pools of rain water which may accumulate do not damage a built-up roof.

9. The panel walls consist of steel sash which occupy the entire width between columns and below which masonry walls are placed.

10. The parapet wall is capped with a coping, the top of which slopes toward the roof so that it will drain toward the roof and not over the face of the building.

For an interior view of a building of the beam and girder type see Fig. 184.

Typical details of a building of the flat-slab type are shown in Fig. 200. The features which should be noted in this figure are:

1. The substitution of flat-slab construction for the beam and girder construction shown in the previous figure.

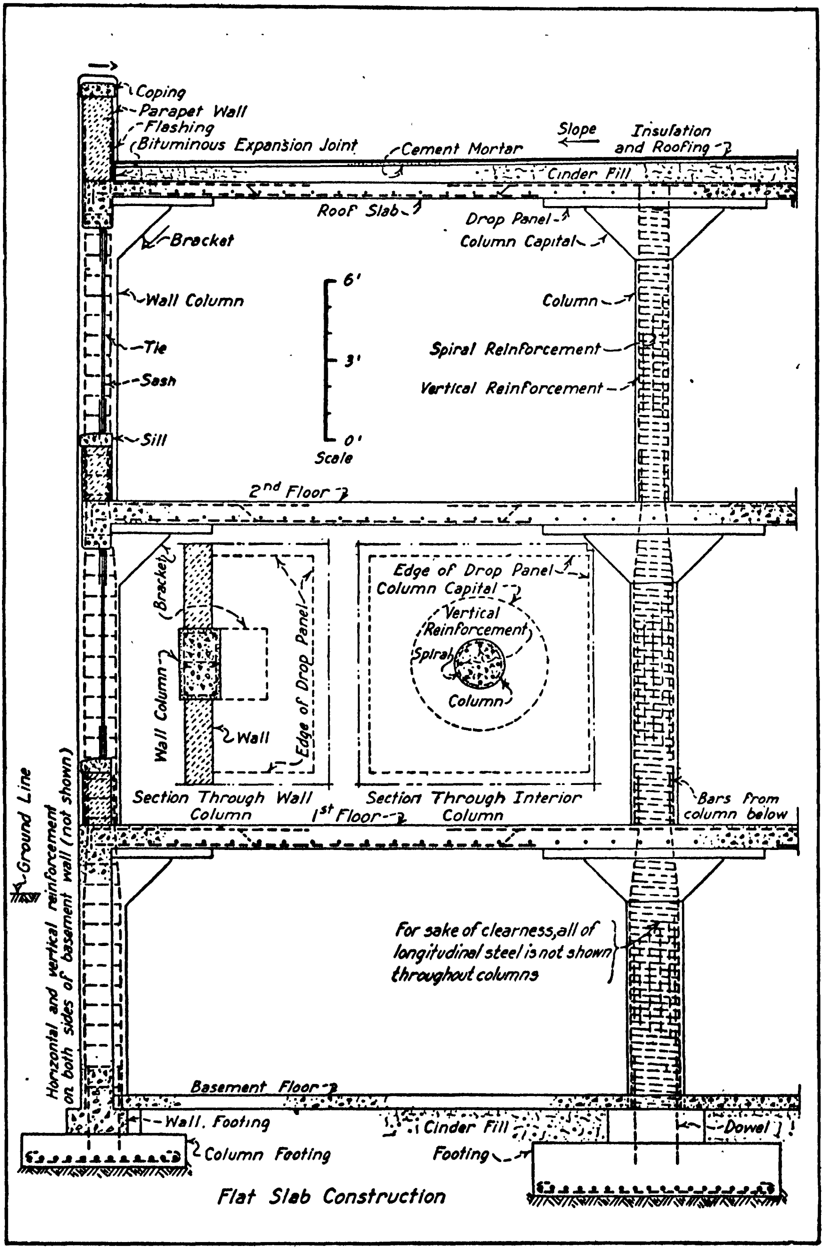


FIG. 200. Reinforced-Concrete Flat-Slab Construction

2. The drop panels and the column capitals of the interior columns.

3. The brackets and drop panels of the exterior columns.

4. The spiraled interior columns. For clearness, only a part of the longitudinal bars are shown in the elevation but they are all shown in the section.

5. The tied wall columns. Since these columns are rectangular they are provided with intermediate ties. Spirally reinforced columns might have been used.

Other features are the same as the corresponding features of the beam and girder type which have just been explained.

For an interior view of a building of the flat-slab type, see Fig. 185.

Walls. Reinforced-concrete walls are discussed in Art. 30.

Wind Stresses. For a building whose width is large in proportion to its height, wind stresses are not an important factor, but for a tall slender building they must be given consideration. The reinforced-concrete frame is a rigid structure in the members of which lateral forces produce flexural stresses and direct stresses. These stresses are provided for by increasing the sections and reinforcement as required and not by special details as used in steel construction.

Earthquake Stresses. The discussion of earthquake resistance given in Art. 48 applies to reinforced-concrete buildings as well as to buildings with frames of structural steel.

Expansion Joints. The following material on expansion joints is quoted from the 1940 Joint Committee Report:[1]

a. Expansion joints are expensive and in some cases difficult to maintain. They are, therefore, to be avoided if possible. In relatively short buildings, expansion and contraction can be provided for by additional reinforcement. No arbitrary spacing for joints in long buildings can be generally applicable. In heated buildings joints can be spaced farther apart than in unheated buildings. Also, where the outside walls are of brick or of stone ashlar backed with brick, or where otherwise insulated, the joints can be farther apart than with exterior walls of lower insulating value.

b. In localities with large temperature ranges, the spacing of joints for the most severe conditions of exposure (uninsulated walls and unheated buildings) should not exceed 200 ft. Under favorable conditions buildings 400 to 500 ft. long have been built without joints even in localities with large temperature ranges.

c. In localities with small temperature ranges, the spacing of joints for unheated buildings or with uninsulated walls should not exceed 300 ft. In such localities buildings up to 700 ft. long have been successfully built without joints where other conditions were favorable.

d. In roof construction, provision for expansion is an important factor. The joints in the roof may be required at more frequent intervals than in the

other portions of the building because of more severe exposure. In some cases expansion joints spaced 100 ft. apart have been provided in roofs and not in walls or floors.

e. Joints should be located at junctions in L-, T-, or U-shaped buildings and at points where the building is weakened by large openings in the floor construction, such as at light wells, stairs, or elevators. Joints should provide for a complete separation from the top of the footings to the roof, preferably by separate columns and girders.

Fire Resistance. The Joint Committee[1] has divided coarse aggregates for use in fireproofing into two classes in recognition of differences in behavior when subjected to high temperatures. Group 1 includes aggregates predominating in materials which change in volume a relatively small amount when exposed to high temperatures and also includes cinders low in combustible materials. Group 2 includes aggregates containing substantial proportions of particles which change in volume a relatively large amount when exposed to high temperatures and also includes cinders containing combustible material in excess of the desirable minimum. It is stated that adequate fireproofing can be obtained with the materials in either group so long as the differences in their characteristics are taken into account in the design of the concrete.

Group 1 aggregates include blast-furnace slag, limestone, calcareous gravel, trap rock, burnt clay or shale, cinders containing not over 25 per cent combustible material and not over 5 per cent volatile material, and other aggregates which pass the test required by the Committee and containing not over 30 per cent of quartz, chert, flint, and similar materials.

Group 2 aggregates consist of granite, quartzite, siliceous gravel, gneiss, cinders containing more than 25 per cent but not more than 40 per cent combustible material and not more than 5 per cent volatile material, and other materials meeting the Committee's specifications and containing more than 30 per cent of quartz, chert, flint, and similar materials.

The thicknesses of concrete required by the Joint Committee to protect metal reinforcement are as follows:

In ribbed-floor construction where ribs are spaced not more than 30 in. in the clear, are formed between permanent masonry-filler blocks, or between permanent or removable forms, and have a protection of ¾ in. of portland cement or gypsum plaster applied directly to the ribs and masonry fillers, or to metal lath attached or suspended below the ribbed construction, the fire protection requirements for the ribs should be those indicated in the table for solid slabs.

THICKNESSES OF CONCRETE REQUIRED TO PROTECT METAL REINFORCEMENT FOR VARIOUS FIRE-RESISTANCE RATINGS

Member	Minimum Thickness of Concrete in Inches			
	4 hr.	3 hr.	2 hr.	1 hr.
Columns, beams, girders, unprotected ribbed slabs				
Group 1, aggregate	1½	1½	1½	1
Group 2, aggregate	2	1½	1½	1
Solid slabs				
Group 1, aggregate	¾	¾	¾	¾
Group 2, aggregate	1	¾	¾	¾

Moisture Protection. The Joint Committee[1] requires that reinforcement near the surfaces of footings and other principal structural members in which concrete is deposited directly against the ground be protected by at least 3 in. of concrete. The protection at other surfaces exposed to the ground or to severe weathering conditions should be 2 in., and at the under sides of slabs exposed to the weather it should be 1 in. Where wire mesh or exposed metal is used for reinforcement in protective coatings or in columns, beams, or girders, the minimum covering should be 1½ in. for structures exposed to water, ground, or weather, and ¾ in. for unexposed structures.

REFERENCES

1. "Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete," Joint Report of a Committee Comprising Representatives of American Society of Civil Engineers, American Society for Testing Materials, Portland Cement Association, American Concrete Institute, American Railway Engineering Associations, American Institute of Architecture, 1940.

2. WRIGHT, WILLIAM T.: "Hollow Concrete Rigid Frames Support Auditorium Roof," *Engineering News-Record,* Apr. 15, 1937.

3. TEDESKO, ANTON: "Large Concrete Shell Roof Covers Ice Arena," *Engineering News-Record,* Apr. 8, 1937.

4. CRANE, THEODORE, and THOMAS NOLAN (the late): "Concrete Building Construction," John Wiley & Sons, 1927.

5. SUTHERLAND, HALE, and WALTER W. CLIFFORD (the late): "Introduction to Reinforced Concrete Design," John Wiley & Sons, 1926.

6. TURNEAURE, F. E., and E. R. MAURER: "Principles of Reinforced Concrete Construction," Fourth Edition, John Wiley & Sons, 1935.

7. PEABODY, DEAN, JR.: "The Design of Reinforced Concrete Structures," John Wiley & Sons, 1936.

CHAPTER IX

FLOOR CONSTRUCTION, FLOOR SURFACES AND WALL COVERINGS

ARTICLE 55. TYPES OF FLOOR CONSTRUCTION

Wood Floors on Wood Joists. The most common form of floor construction for non-fireproof buildings consists of wood joists supporting a 1-in. wood sub-floor, and a matched wood finished floor as described in Art. 42, preferably with a layer of building paper or other material between the sub-floor and the finished floor as shown in Fig. 201*a* and Figs. 133 to 136 inclusive. Magnesite composition as described in Art. 59 may be used in place of matched flooring, or the construction may be changed to receive tile, terrazzo, or other material.

The joists are usually 2 in. wide, and from 6 to 14 in. deep. For heavy loads the joists may be 3 or 4 in. wide. Wider joists are used in slow-burning construction, which is considered under another heading. Where wood lath is to be used the spacing must be such that a joist will come every 4 ft. to avoid waste, the lath being 4 ft. long. For this reason the usual spacings are 12 and 16 in., 24 in. being too great a space for good results with wood lath. Light metal lath requires a spacing not greater than 12 in., but greater spacing may be used with heavier lath. In some cases, 1- by 2-in. furring strips, properly spaced for lath, and running at right angles to the joists, are nailed to the under side of the joists to receive the lath. Consequently, the spacing of the joists is independent of the lath. This construction enables fire to spread rapidly across the joists, so is objectionable. Another objection to the use of wood furring strips, nailed to the under side of wood joists, is the tendency for these strips to become loose and permit the ceiling to fall as the joists dry out and their grip on the nails weakens.

An important function of the sub-floor is to provide a floor during the early stages of construction, the finished floor being laid after the plastering is done. A sub-floor makes the floor more substantial, more fire-resistant, more soundproof, and warmer. When a sub-floor is used, there is a tendency to nail the finished floor to the sub-floor rather than to the joists. This practice is objectionable because the finished floor does not remain in place as well when nailed to the sub-floor and tends

to squeak. There is also a tendency to lay the finished floor parallel with the joists, which is very objectionable. The sub-floor should be laid diagonally, or if strips are placed over the joists, the finished floor

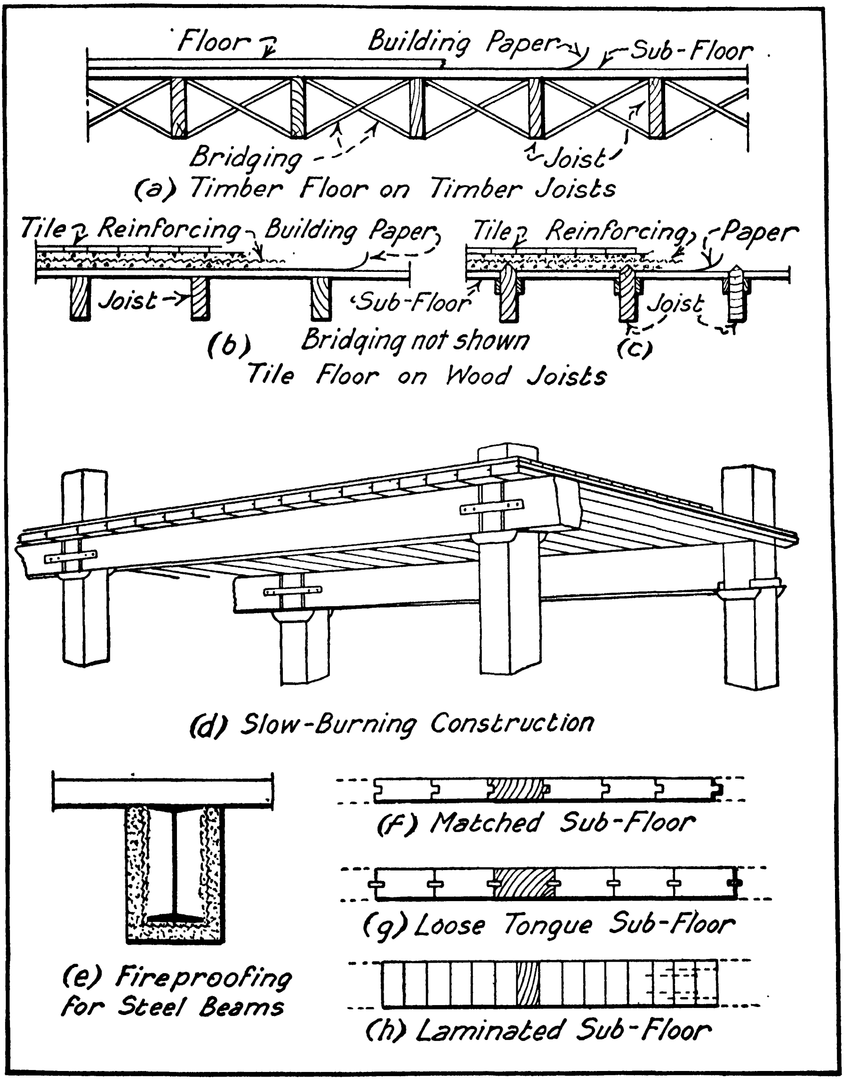


Fig. 201. Wood Floor Construction

and sub-floor may both be laid at right angles to the joists, the strips overcoming the uneven places in the sub-floor. The sub-floor may be of ordinary sheathing, matched boards, shiplap, or plywood. Some-

times the sub-floor is omitted entirely to decrease the cost, in which case the finished floor would probably have to be laid before plastering, during which operation it must be protected from dirt and water. In any case, it will absorb moisture given off by the plaster. This will cause swelling which will be followed by shrinking and the opening of the joints.

The layer between the sub-floor and the finished floor may be omitted entirely or may consist of building paper, asphaltic felt, asbestos paper, plaster board, or of concrete 1½ to 2 in. thick reinforced with a light wire mesh or expanded metal. Some form of layer should always be used; and, if the cost will permit, the increase in fire-resistance due to a layer of heavy asbestos paper or plaster board will warrant the additional expenditure.

The joists are held in a vertical position by cross bridging as shown in Fig. 201*a*, one row being used where the span of the joists is over about 8 ft., and two rows where over 16 ft. Cross bridging also serves to distribute concentrated loads over several joists.

If a wood sub-floor is laid before rain is excluded from the building, and it usually is, provisions should be made for the swelling of the sub-floor or the exterior walls may be cracked and pushed out and other damage may be caused. To avoid this difficulty, spaces ¼ to ½ in. may be left between the boards, or every tenth or twelfth board may be omitted at first and placed after the building is under cover.

Where a tile floor is to be placed on wood-joist construction the floor is usually designed to carry a reinforced-concrete slab, as shown in Fig. 201*b*, to act as a base for the tile. The construction shown in Fig. 201*c* is also used, but is more likely to produce cracks than the construction in Fig. 201*b*. A thin-setting bed for floor tile which does not require special construction is described in Art. 60.

This type of floor construction is used in residences and other buildings of ordinary construction, and may be used in buildings with steel frames. It is inexpensive, light, and may be made sufficiently strong for heavy loads, but is very combustible. If protected on the under side by plaster or metal lath its resistance to fire is increased.

Heavy Wood Sub-Floor on Wood or Steel Beams. Wood sub-floors varying in thickness from 3 to 10 in., depending upon the loading and span, may be supported directly by girders running between columns, as shown in Fig. 201*d* and Figs. 137 and 138, or by beams which are supported by the girders, as shown in Fig. 139 and described in Art. 42. In the first arrangement the lateral spacing of columns must not be over 10 or 12 ft. on account of the heavy sub-floors required for longer spans. In the second arrangement the beams are spaced 4 ft.

or more apart, and the column spacing is not restricted by the strength of the sub-floor.

To secure resistance to fire, wood beams and girders are made at least 6 in. wide, and at least 10 in. deep, even though the loads may not require beams of this size. If steel beams are used, they should be protected against fire, as shown in Fig. 201*e*, the beam first being covered with metal lath and then plastered.

Heavy wood sub-floors may be of three types, i.e., *matched*, as shown in Fig. 201*f*; *loose-tongue*, as shown in Fig. 201*g*; or *laminated*, as shown in Fig. 201*h*. The matched floor may be used for thicknesses of 3 or 4 in., but for greater thicknesses the waste in matching becomes so large that the hardwood loose tongue may be more economical. This loose tongue is also called a *slip tongue* or *spline*.

Floors 4 in. and over in thickness may be constructed by laying 2-in. lumber on edge, and securing the adjacent pieces together with spikes spaced about 18 in., 2 by 4's being used for a 4-in. floor, 2 by 6's for a 6-in. floor, etc. This type of floor is known as a *laminated floor*. A laminated floor is easier to lay than a heavy loose-tongue floor, for the pieces being smaller are more easily handled and drawn into position; but more feet, board measure, are required because 2-in. material is really $1\frac{5}{8}$ to $1\frac{3}{4}$ in. thick. The cost of the loose tongue is saved in the laminated floor.

When the details are properly worked out, this type of construction, using wood in large masses, is called *slow-burning construction* on account of the slow progress made by fire in burning the heavy timber.

Concrete Slabs on Light Steel Joists. Light steel joists are described in Art. 45 and illustrated in Fig. 142. Open-web joists are spaced 12 to 24 in. apart. They may support a thin concrete slab reinforced with expanded metal lath placed over, and fastened to, the tops of the joists, as shown in Fig. 202*a*, the metal lath serving as the bottom form for slab. Wood nailing strips running perpendicular to the joists and fastened to the joists, as shown in Fig. 202*b*, may be provided if wood flooring is to be used with a thin concrete slab. Instead of providing nailing strips in the concrete slab, nailing concrete, as described in Art. 10, may be used. If wood floors are to be used, *nailer joists* are available with a wood nailing strip anchored along the top flange of each joist to permit the nailing of the floor to the joists, as shown in Fig. 202*c*. Wood flooring may be fastened directly to the nailing strip shown in Fig. 202*b* and *c* or else a wood sub-floor may be used. If a sub-floor is used, it should be laid diagonally and the flooring should be nailed through the sub-floor into the nailing strips. This procedure reduces the tendency of the floors to cup or squeak.

The light rolled-steel sections manufactured especially for use as floor and roof joists may be used in the same manner as the open-web joists, but nailer joists of this type are not available. The nailing strips are fastened to the joists on the job.

Bridging is required for light metal joists to correspond to that used with wood joists. This bridging may consist of light steel rods or strap iron and is so arranged that the tensile resistance of the members is that which is effective.

Ceilings may be provided on the under side of these types of floor construction by plastering over metal lath, or other plaster base, fastened to the under side of the joists. Such ceilings improve the appearance and are usually required for that purpose as well as to increase the resistance to fire.

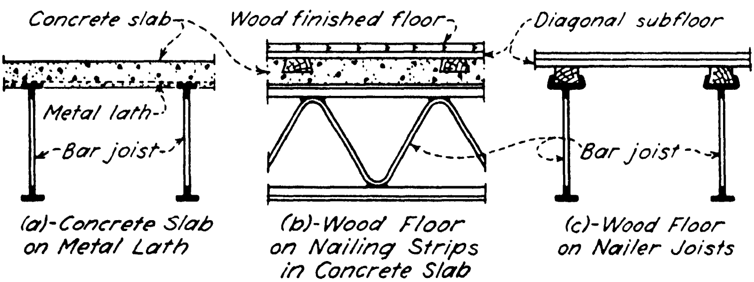


FIG. 202. Concrete and Wood Floors on Open-Web Joists

Other Types. Reinforced-concrete slabs supported by steel beams are described in Art. 52 and illustrated in Fig. 183.

Reinforced-concrete slabs supported by reinforced-concrete beams are described in Art. 52 and illustrated in Fig. 183.

Reinforced-concrete flat-slab construction is described in Art. 52 and illustrated in Fig. 186.

Reinforced-concrete ribbed slabs supported by steel or reinforced-concrete beams are described in Art. 52 and illustrated in Figs. 187 and 188.

Hollow clay-tile arches supported by steel beams are described in Art. 27 and illustrated in Fig. 84.

Brick arches supported by steel beams are described in Art. 25 and illustrated in Fig. 70*a*. Reinforced brick masonry floor slabs are illustrated in Fig. 71.

ARTICLE 56. GROUND-FLOOR CONSTRUCTION

The wearing surfaces for floors are discussed in Arts. 58 to 63. Several of these wearing surfaces may be used on floors resting on the ground if the sub-floor and base are properly constructed. The various types of bases for ground floors will be discussed in this article.

Unless the ground on which the floor is to be placed is free from water, and certain to remain so, an effective drainage system should be installed under the floor. This system may consist of lines of drain tile or sewer tile with open joints laid at intervals under the floor and connected to a sewer or drain to conduct the water away. A layer of gravel, cinders, or crushed rock, from 4 to 6 in. thick, is placed under the base to permit the water to reach the drains. If the ground is not likely to contain water the drainage system is unnecessary, and the porous base of crushed rock, gravel, or cinders will tend to keep the dampness from the ground from reaching the base by capillary action. A layer of asphaltic felt laid on top of the porous layer will assist in making a dry floor if a concrete base is used. See Arts. 22 and 23.

The bases used to support the wearing surface of ground floors are usually of two general types, portland cement concrete, or bituminous concrete. A portland cement concrete base is from 4 to 6 in. thick. If the wearing surface is to be of concrete, the floor is sometimes divided into 6- or 8-ft. blocks to prevent cracks due to changes of temperature or shrinkage. It is common practice to place concrete basement floors without joints; but, under any conditions, a joint should be provided at each side of a doorway if the cement floor is to continue through the door, and joints should be provided at all re-entrant angles so that the floor is made up of rectangular blocks even though these blocks are quite large. If such joints are not provided, shrinkage cracks will invariably develop in these locations.

If the wearing surface is to be of brick, a cushion of sand, cement mortar, or bituminous mastic is used between the base and the brick. Clay-tile wearing surfaces are placed on a layer of cement mortar. Such surfaces as linoleum or cork carpet are cemented directly to the concrete base, the surface of which must be finished as smoothly as though it were going to be used for a wearing surface. If there is any possibility of the floor's being damp, it should be waterproofed if such surfaces as linoleum or cork carpet are to be used. Asphalt tile or mastic is the only wearing surface of that general type suitable for use on a concrete base below the ground level but clay tile, terrazzo, and brick are entirely satisfactory. Wood flooring is not usually satisfactory under these conditions.

If a wood-block wearing surface is to be placed on a concrete base, a thin dampproof layer of asphalt mastic must be placed on the concrete. The wood blocks are bedded on this layer before it has hardened. If a wood matched-flooring wearing surface is to be used, a sub-floor consisting of a layer of 3-in. planks side-nailed together is placed on the damp-proof layer before it has hardened. The matched flooring is placed on the wood sub-floor, the flooring being placed at right angles to the plank. See Fig. 203a. A more substantial sub-floor may be secured by replacing the layer of 3-in. plank with two layers of 2-in.

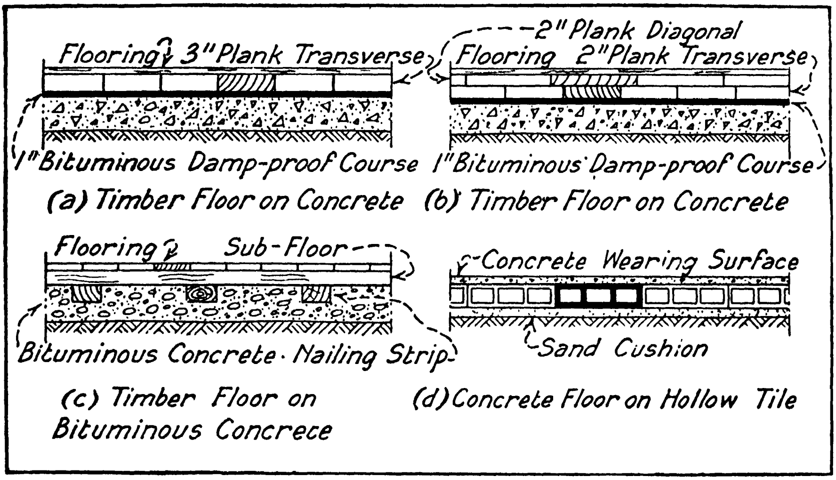


FIG. 203. Ground-Floor Construction

plank, the top layer being laid diagonally and the wearing surface at right angles to the bottom layer. See Fig. 203b. The sub-floors described above may be made of material either thicker or thinner than that mentioned above if the conditions warrant. In all cases it is desirable to give the wood in the sub-floor a preservative treatment. Wood nailing strips or sleepers should never be embedded in a concrete base for a ground floor, for they will soon decay. A base of *bituminous concrete* may be used in place of the portland cement concrete with a wearing surface of wood or brick. The bituminous concrete corresponds to portland cement concrete with tar or asphalt for a cementing material instead of portland cement. The materials are mixed and placed hot. Wood nailing strips or sleepers may be embedded in bituminous concrete with a wood sub-floor on a dampproof layer nailed to these strips as shown in Fig. 203c.

The base of a ground floor may consist of a layer of hollow clay-tile blocks laid on a sand cushion resting on firmly compacted earth or gravel as shown in Fig. 203*d*. These tile should be dense and hard-burned. A concrete wearing surface an inch or more in thickness would be used with this type of base. The air space in the tile insures a dry floor. If water is present, a drainage system must be installed as with other types.

ARTICLE 57. SELECTING TYPE OF FLOOR CONSTRUCTION

In selecting a type of floor construction to use in a building the following factors should be taken into consideration:

a. General type of construction used in the building.
b. Plan of building.
c. Floor loads.
d. Resistance to fire.
e. Ceiling; flat or exposed beams.
f. Direct cost.
g. Indirect cost; effect of weight and thickness.
h. Floor covering.
i. Position of floor; ground floor or above ground.
j. Use of building.

These factors overlap each other in many cases, and their relative importance varies with different classes of buildings.

General Type of Construction. If the beams, girders, and columns are of wood, the floor construction will usually be of wood; if a steel frame is used, the floor construction may be wood, plain or ribbed concrete slabs, or hollow tile or concrete arches; whereas, if the supporting frame is concrete, the floor construction may be plain or ribbed concrete slabs or flat-slab construction. If bearing walls are used throughout, flat-slab construction would of course be impossible. However, this type of construction can be used with exterior bearing walls.

Plan of Building. If the building is divided into panels which are very nearly square, flat-slab construction may prove to be desirable, or the two-way plain or ribbed concrete slab with beams on the four sides of each panel may be seriously considered. If the spans are short, the plain slab might be used; whereas for long spans the ribbed slabs will be found to be more satisfactory. If the building is to be divided into rooms, flat-slab construction is not as satisfactory as it is for undivided areas on account of the interference of the column capitals with the partitions. Concrete ribbed slabs are particularly suitable for long spans. Flat-slab construction is not suitable for irregular plans.

Floor Loads. Light steel joists may be used for light loads, such as those found in apartment houses, office buildings, and schools, but are not suitable for heavy loads. For very heavy loads brick arches might be used, but their use is rare. Flat-slab construction has advantages for heavy loads which it does not possess for light loads.

Resistance to Fire. When a building must be cheaply constructed and resistance to fire is not a decisive factor, ordinary wood-joist construction with wood sub-floor may be used. These conditions prevail in residence construction more than in any other class of building.

In warehouses and many types of industrial buildings, slow-burning construction may offer sufficient resistance to fire and provide a building at a lower cost than that of a fireproof building.

In the congested downtown districts of many cities, building ordinances require fireproof construction; so wood-joist construction and slow-burning construction could not be used. Floors constructed of steel joists, although incombustible, are not sufficiently fire-resistant to be accepted in all cases. Flat-slab construction and plain concrete slabs withstand the action of fire better than ribbed slabs, but the latter are satisfactory. In severe fires the lower shell of hollow tile used in ribbed slabs has been known to split off, and in some cases sheet-steel forms left in place have been expanded by heat and have forced the plastered ceiling off. In these cases the structural value of the floors is not destroyed. Hollow tile, brick, and concrete arches have satisfactory fire-resisting qualities when properly constructed.

The cost of fire insurance is an important factor entering into the choice of floor construction, the rates depending upon the fire resistance of the construction as well as the nature of the contents, the location, and many other factors. The rate is lowered in many classes of buildings by the installation of automatic sprinkler systems which come into action in any part of a building when the temperature in that part is raised by fire.

Ceiling. Ordinary wood-joist construction, flat-slab construction, ribbed concrete slabs, and flat tile arches provide flat ceilings, but plain concrete slabs supported by beams and girders, and segmental arches of brick, hollow tile, or concrete require suspended ceilings if flat ceilings are desired. In addition to their better appearance, flat ceilings offer advantages in fire protection by sprinkler systems and in lighting.

Direct Cost. The direct cost of a floor will be assumed to include the cost of the floor slab, arches, etc., plus the cost of the supporting beams and girders ready to receive any base course required by a wearing surface, but not including the cost of such base, the wearing surface, the plastered ceiling, or the supporting columns and foundations.

On this basis the various types, not including ground floors, may be arranged in the following order according to the direct cost, the least expensive being given first:

1. Light wood-joist construction.
2. Light steel joists with timber floors.
3. Heavy timber construction.
4. Light steel joists and reinforced-concrete slab.
5. Reinforced-concrete slab and beams.
6. Reinforced-concrete ribbed slabs with steel forms.
7. Reinforced-concrete ribbed slabs with clay tile or gypsum tile.
8. Hollow clay-tile arches and steel beams.

The exact order will be affected by local conditions and changing prices of materials and labor, but the list will give a fair idea of relative costs. Where a steel frame is used the supporting beams would naturally be of steel, and with a concrete frame they would be of concrete.

For floors carrying fairly heavy loads and with square or nearly square panels of uniform size, flat-slab construction would probably be placed fourth in the list.

Panels which are square or nearly square may make possible the use of two-way plain or ribbed concrete slabs, which cost less than the corresponding one-way slabs.

Indirect Cost. The indirect cost of a floor will be assumed to include the cost of the base for the wearing surface, the cost of the plastered ceiling, the effect of the weight of the floor on the cost of the columns and foundations, and the effect of the total thickness on the height of the building and therefore on the cost.

If wood flooring is to be used for the wearing surface, light wood-joist and heavy timber construction have a distinct advantage in cost over other forms of floor construction where nailing strips with concrete fill between have to be provided. The closely spaced light steel joists may be covered with nailing concrete and thereby avoid most of this cost, or nailing strips may be placed directly over the joists with a light concrete slab between nailing strips. See Fig. 202. Some forms of wood floors may be cemented directly to carefully finished concrete surfaces, with bituminous cement.

If the wearing surface is to be linoleum, cork, concrete, composition, asphalt tile, light asphalt mastic, cork carpet, rubber, tile, etc., any of the forms of floor construction which provide a concrete top surface are suitable, but the additional cost of providing a finished surface must be considered. With wood-joist or heavy timber construction, a concrete surface would add to the cost; asphalt tile, asphalt mastic, and linoleum,

etc., require a matched floor or plywood; but composition can be laid on the sub-floor.

Clay tile, marble, slate, and terrazzo usually require a concrete foundation; so the various forms of floor construction which provide a concrete top surface are suitable for the installation of these materials without further expenditure, but wood sub-floors require a 2-in. or 3-in. slab which increases the cost considerably. See Fig. 201*b*. However, the thin-setting bed for tile described in Art. 60 may be satisfactory.

Plastered ceilings are provided by applying two coats of plaster directly to the under side of flat tile arches, ribbed slabs with clay or gypsum tile fillers, flat slabs, or plain slabs supported by concrete or fireproofed steel beams. The ribbed slabs and the flat slabs provide a flat ceiling, but the slabs supported by beams necessitate breaks in the ceiling, and the cost of plastering is greater on account of the increased area and the additional labor required in finishing around the edges of the beams. Wood joists, heavy timber construction, metal joists, and ribbed slabs with steel forms require lath and preferably three coats of plaster or plaster board and two coats of plaster on the under side to provide a plastered ceiling. The ceiling supported by wood joists, ribbed slabs with steel forms, and metal joists will be flat; whereas the ceiling supported by heavy timber construction will probably follow around the beams. The cost of the lath and the additional cost of plaster should be considered in selecting the floor construction.

It is evident that the heavier slabs will require a more costly supporting structure. Wood and metal joists have the advantage in this respect, and ribbed slabs with clay-tile fillers as well as concrete slabs supported by beams are at a disadvantage.

The minimum height of building for given clear ceiling heights is obtained with flat-slab construction. Ribbed slabs and metal joists are also satisfactory in this respect if the girders running one way come over partitions, as they usually do. Concrete slabs supported on beams and girders take up the most room. Any increase in height means an increase in the cost of walls, columns, elevators, stairways, and many items, individually small, which may reach a total worth considering.

Where the cost is an important factor in the selection of the floor construction, comparative estimates of the various types will usually be made.

Floor Coverings. It is possible to place any floor covering on any form of floor construction, but the cost of preparing the supporting floor to receive the wearing surface must be considered, as has just been explained. Many types of floor covering are available. They are discussed in Arts. 58 to 63 which follow.

Use of Building. The use which is to be made of a building enters into the choice of the general type of construction, as explained in Art. 2. The use is a determining factor in the selection of the particular type of floor construction only to the extent that the desirability of flat ceilings, the need for durable and fireproof construction, the magnitude and character of the floor loads, and such factors are influenced by the use.

ARTICLE 58. WOOD FLOORING

Types. Wood flooring is available in the following forms:

a. Strip flooring consisting of long narrow pieces or strips with tongue-and-groove joints along the sides and, commonly, along the ends also. Generally called *matched flooring* or, simply, *flooring.*

b. Plank flooring consisting of wider boards than strip flooring with tongue-and-groove joints along the sides and ends.

c. Parquet flooring consisting of short narrow boards cut to form patterns or mosaics.

d. Industrial wood block flooring consisting of heavy pieces cut in lengths of from 2 in. to 4 in. forming blocks which are set with the ends of the grain exposed to wear.

e. Fabricated wood block flooring consisting of small square or rectangular blocks formed by fastening short pieces of strip flooring together, tongue-and-groove joints being provided on all sides.

Methods of Fastening. Wood flooring may be nailed to wood joists through a wood sub-floor. *Nailing strips* are often provided on concrete floor slabs, hollow-tile arches, and other types of supporting floors. These strips may be beveled, as shown in Fig. 204*a*, and embedded in concrete which holds them in place. Nails may be driven into the sides of the strips to grip the concrete. Expansion bolts or screws may be used as anchors. Special clips to receive the strips may be embedded in the top of the slab when the slab is poured or the strips may be nailed to other strips at right angles to them, the whole grid being embedded in concrete as shown in Fig. 204*b*.

Preparations known as *nailing concrete,* as described in Art. 10, are on the market and may be used, with more or less satisfactory results, instead of nailing strips. These concretes are of special composition which permits nails to penetrate. They are usually applied in a layer 2 in. thick with the top surface struck very accurately to receive the finished floor.

Industrial and fabricated wood blocks are usually cemented, and parquet, plank, and short pieces of strip flooring are often cemented to concrete floors, or to a concrete fill over hollow-tile arches, with an

asphalt mastic. These mastics are of two types, i.e., the *hot mastic,* which is made fluid by heating; and the *cold mastic,* which is made fluid by a solvent. The hot mastic is applied to the slab and the flooring is bedded in it before it cools. The cold mastic gradually solidifies by the evaporation of the solvent after the flooring is placed. The layer of asphalt mastic is called an *underlayment.*

Flooring which is provided with tongue and groove is *blind-nailed* to joists or nailing strips, as shown in Fig. 204*d,* so that the nail does not show on the surface. In order to avoid injuring the floor by the last

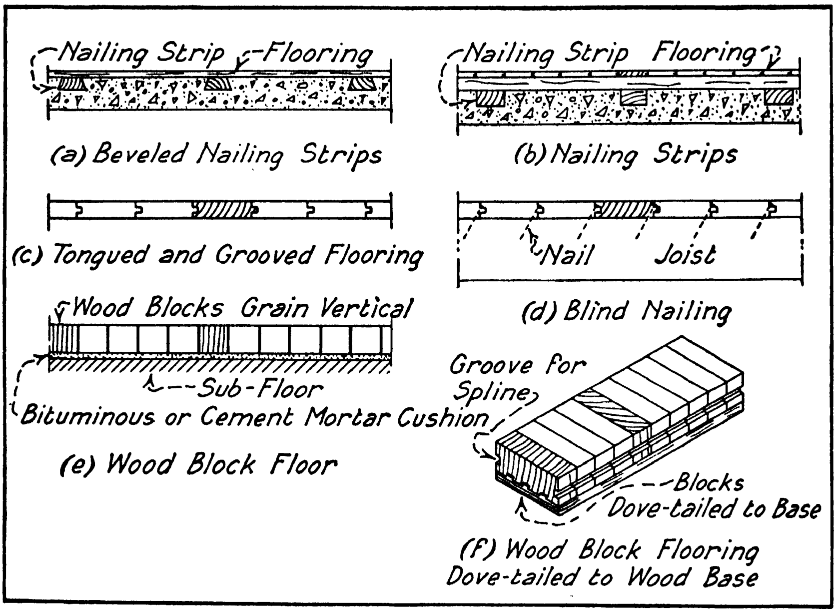


Fig. 204. Wood Floor Surfaces

blow of the hammer which drives the nail home, a square bar, or the square end of a nail set, may be placed in the corner and against the nail head to receive the hammer blow and protect the flooring. Special flooring nails, with small heads, as illustrated in Fig. 101*d,* are used in blind nailing. The ends of plank flooring are commonly screwed to the sub-floor, the heads of the screws being sunk in holes bored part way in the wood. These holes are filled with wood plugs which are specially manufactured for that purpose. The plugs are quite visible, but this is the effect desired. To provide for expansion, plank flooring should be laid with temporary metal spacers $\frac{1}{32}$ in. thick placed in the

cracks between the planks. Parquet floors are fastened to wood subfloors with brads driven through the face, the brads being set by driving their heads below the surface with a *nail set*. The holes above the heads are filled with putty.

Kinds of Wood. Strip flooring, plank flooring, parquet flooring, and fabricated wood blocks are available in the hardwoods: white and red oak, maple, beech, birch, and walnut. The oaks may be *plain-sawed* or *quarter-sawed,* often called *vertical-grain* or *edge-grain.* Strip flooring is also available in the softwoods: fir, yellow pine, white pine, cypress, and many others listed in the table in Art. 8. Only the quarter-sawed or vertical-grain softwoods should be used, except in the cheapest construction or for attics or other floors which are little used.

Industrial wood blocks are usually made of yellow pine or redwood.

Size, Grades, etc. *Strip flooring,* which is usually called flooring or matched flooring, is usually $\frac{25}{32}$ or $\frac{13}{16}$ in. thick. The most common widths of hardwood flooring are $2\frac{1}{4}$, 3, and 4 in. which have exposed faces of $1\frac{1}{2}$, $2\frac{1}{4}$, and $3\frac{1}{4}$ in.; and the common widths of softwood flooring are 3 and 4 in. with exposed faces of $2\frac{3}{8}$ and $3\frac{1}{4}$ in. Oak flooring $\frac{3}{8}$ in. and $\frac{1}{2}$ in. thick and maple flooring $\frac{3}{8}$ in., 1 in., and $1\frac{1}{4}$ in. thick are available. Thicker maple flooring may be obtained on special order. The thinner flooring is for use over old floors and is not usually satisfactory for use in new buildings because of its tendency to squeak. Thick maple flooring is suitable for severe usage such as in warehouses, factories, and gymnasiums. Heavy trucking may break off the tongues or lower part of the grooves of ordinary strip flooring. Maple, beech, and birch flooring is furnished in three grades depending upon the quality, i.e., first, second, and third. Oak flooring is available in five grades, i.e., clear, sap clear, select, No. 1 common, No. 2 common.

Plank flooring is usually $\frac{13}{16}$ in. thick and from 3 to 8 in. wide. It is commonly used in random widths and is known as *colonial plank flooring.* The edges are slightly beveled to form V joints.

Parquet flooring is usually $\frac{5}{16}$ in. thick and 1, $1\frac{1}{2}$, or 2 in. wide with square edges, but $\frac{13}{16}$-in. flooring, $2\frac{1}{4}$ in. wide, which is side- and end-matched is also available.

Individual wood blocks vary in thickness from 2 to 4 in., depending upon the severity of the service. The width is from $2\frac{1}{4}$ to 4 in. and the length from 4 to 9 in. The blocks are often provided with wood or metal splines and may be assembled in strips, up to 8 ft. in length, whose width equals the length of a single block, as shown in Fig. 204*f*. The joints between the blocks are filled with bituminous filler. Expansion spaces about 1 in. wide should be provided against all walls and around all columns, thresholds, and permanent fixtures.

Fabricated wood blocks are made of flooring usually $\frac{13}{16}$ in. thick, but $\frac{1}{2}$-in. and 1-in. thick blocks are also available. The squares vary in size from $6\frac{3}{4}$ in. to $11\frac{1}{4}$ in., and the rectangles are about 6 in. by 12 in. The number of strips to a block may be 4, 5, or 6. The strips are held together with metal backing strips Expansion spaces should be allowed around all walls, columns, thresholds, and permanent fixtures, the width being about $\frac{1}{16}$ in. for each foot of width or length. These spaces may be partly filled with asphalt mastic, completely filled with cork strips, or may contain springs to hold the edge blocks in place. If a room is much longer than it is wide, square blocks should be laid diagonally. The blocks are commonly sanded, filled, waxed, and polished at the factory.

Uses. Wood floors are warm and elastic and so are not tiresome to work on. They are clean and, if proper selection is made and they receive proper care, they are durable. They may be made attractive in appearance and are suitable, from that point of view, for the highest type of use. Wood floors supported by fireproof construction are used in many buildings classed as fireproof because under these conditions they burn very slowly in case of fire. However, they are not used in the highest type of fireproof buildings. They are probably the most satisfactory floors for residences and are usually the cheapest.

Wood floors should not be placed until after all concrete work and plastering have been completed and the building has had a chance to dry out. The flooring should not be stored in the building during this period. The cracks in wood floors which are permitted to absorb moisture, before they are laid, will open up as the wood dries out. Special care should be used in wood floors laid over concrete to make sure that the concrete has dried out. An asphalt mastic dampproofing layer should preferably be placed over the concrete.

ARTICLE 59. CONCRETE, TERRAZZO, AND MAGNESITE COMPOSITION

Concrete.[1] Concrete wearing surfaces are used very widely where the structural part of the floor is of concrete. The wearing surface may be an integral part of the construction beneath, or it may be added as a separate layer. If the wearing surface is placed before the base has set, a thickness of $\frac{3}{4}$ in. to 1 in. is satisfactory; but, if placed after the base has set, the thickness should be 1 in. to $1\frac{1}{2}$ in., and the surface of the base should be roughened, thoroughly cleaned, and coated with cement grout just before the wearing surface is placed. This is done to secure a bond between the wearing surface and the base, but the results are uncertain.

The wearing surface which is an integral part of the floor may be considered as contributing to the strength of the structure; whereas a wearing surface which is added can not be so considered and its weight increases the dead load which must be carried by all the beams, columns, and foundations. In spite of this disadvantage, a separate wearing surface may be cheaper than the integral wearing surface for it is placed after the rough work on the building has been completed, and does not need to be protected as carefully as the integral surface. The conditions which exist while the structural part of the floor is being placed are such that the accuracy required of a finished floor is difficult and expensive to secure.

A truer surface can be secured with the separate wearing surface as the deflection due to the weight of the floor and the yielding of the forms has occurred before the surface is placed, and any discrepancies can be taken up in the wearing surface. The separate wearing surface is sometimes made thick enough to permit the placing of electrical conduits, plumbing pipes, etc., on top of the structural slab. This is a convenience, but requires considerable extra material and a more substantial design.

The coarse aggregate is excluded from the wearing surface, and a richer mixture than that used in the structural parts is used. The aggregate grains and not the cement resist the wear, and so the grains should have a high resistance to abrasion. Beyond a certain limit, an increase in the amount of cement reduces the wearing qualities of a surface and increases the tendency to crack. Usually the mixture or *topping* for the wearing surface consists of 1 part cement to not less than 2, or more than 3, parts fine aggregate.

For surfaces subjected to severe wear, the mixture should be 1 part cement, not more than 1 part fine aggregate, and not more than 2 parts coarse aggregate with a maximum size of ½ in.

Cement wearing surfaces or topping must be carefully laid using a minimum amount of water, troweling as little as possible and protecting against drying out for at least ten days. Excessive troweling brings excess water and laitance to the surface, causing hair cracks to form and the floor to give off dust which is objectionable. This is called *dusting*. Topping applied to a hardened base should be struck off and compacted by rolling or with tampers or vibrators and finished with a steel trowel. The use of dry cement or cement and fine aggregate sprinkled on the surface to stiffen the mix or absorb excess moisture is objectionable because it may cause hair-cracking, scaling, or dusting. Dusting may be prevented or remedied somewhat by the use of *floor hardeners* and other preparations or by painting.

Painted surfaces are satisfactory when the amount of wear is small, but, where subjected to severe use, frequent painting is required. Special paints are manufactured for use on cement floors. A cement-colored paint, of course, shows the wear less than paint of any other color. Paint should not be applied until after the floor has been in place three or four months. Before painting, the surface should be thoroughly scrubbed with a 10 per cent solution of muriatic acid and washed so that the acid is completely removed. The floor should then be allowed to dry before the paint is applied. Paint for the first coat is thinned. Three coats are usually required.

Cement wearing surfaces are sometimes colored and marked off to imitate tile. Colored cement floors finished with wax may be attractive in appearance

If artificial coloring matter is used, only those mineral colors should be employed which will not appreciably impair the strength of the cement.

Mineral coloring material is preferred to organic coloring material, because the latter fades more than mineral colors and may seriously reduce the strength of concrete. Mineral coloring may reduce the strength of concrete somewhat, but where the quantities used are less than 5 per cent this is not serious. The use of colored aggregates is preferable in obtaining color effects, the surface of the floor being brushed or ground to expose the aggregate.

Cement floors are inelastic and cold and tiresome to work on, but they are durable if well constructed, are easily cleaned, and are relatively inexpensive. Cement wearing surfaces should not be used over wood sub-floors without taking special precautions to prevent cracking. The construction should be similar to that used for tile floors, as shown in Fig. 201*b*.

A cement wall base is commonly used with cement floors. If a separate wearing surface is used, the wall base may be placed at the same time as the wearing surface with a curving fillet at the junction. This facilitates cleaning. A cement base will not adhere to lime plaster, hard wall plaster, gypsum blocks, Keene's cement, or plaster board. The backing should be brick, stone, hollow tile, concrete, or metal lath.

A cement floor is sometimes called upon to serve the double purpose of a floor and a roof. Under these conditions, a built-up roofing, as described in Art. 71, is placed on the structural slab. A wearing surface, consisting of a concrete slab about 3 in. thick, is placed over this roofing and is divided into sections not over 16 ft. square by expansion joints about ¾ in. wide with a bituminous filler. Quarry tile, stone flagging, and slate are also used as wearing surfaces over built-up roofing.

Terrazzo.[1] Terrazzo wearing surfaces are constructed in a manner similar to concrete wearing surfaces, but a special aggregate of marble chips or other decorative material is always used and this aggregate is exposed by grinding the surface.

The mortar-base course should be at least $1\frac{1}{4}$ in. thick and should be composed of 1 part portland cement and 4 parts of sand with only enough water to produce a mortar of the stiffest consistency that can be struck off accurately with a straightedge.

The *mortar base* can be placed directly on the concrete slab and bonded to it by first cleaning this slab, thoroughly wetting it, and applying a thin coat of neat cement broomed into the surface for a short distance ahead of placing the mortar base; or the surface of the slab can first be covered with a thin smooth layer of fine dry sand about $\frac{1}{4}$ in. thick, on which is placed a layer of waterproof paper with end and side laps of at least 1 in., on which the mortar base is placed.

The mortar base is struck off at least $\frac{3}{4}$ in. below the finished floor level. Metal *dividing strips* are inserted in the mortar base, before it hardens, in positions which will control the cracking and conform to the design or pattern desired. The tops of dividing strips should extend at least $\frac{1}{32}$ in. above the finished floor level so that they can be ground down flush with the floor surface when the terrazzo is being ground.

The *terrazzo mixture* should consist of 1 part of gray, white, or colored portland cement, according to the decorative effect desired, to not more than 2 parts by weight of marble chips, other decorative aggregate or abrasive aggregate, or such a mixture of any of these as is desired. The amount of water used should be such as to produce a workable plastic mix. Wet mixtures do not produce good results. Any special coloring agents should be mineral pigments.

After the mortar base has hardened enough to stand rolling, the terrazzo mixture should be placed to the level of the tops of the dividing strips and struck off. It should then be rolled in both directions to secure a thorough compacting. Additional aggregates of the desired color should be spread over the surface during the rolling process until at least 70 per cent of the finished surface is composed of aggregate. As soon as the rolling is completed, the surface should be floated and troweled once without attempting to remove trowel marks. Further troweling is objectionable.

After the terrazzo has hardened sufficiently to hold the aggregate firmly, it should be ground by hand or with a grinding machine, the floor being kept wet during the process. The material ground off should be removed by flushing with water. Any air holes or other defects

should be filled with thin cement paste spread over the surface and worked in. After the paste has hardened for at least 72 hours, the floor surface should receive its final grinding. It should be kept continuously wet for at least ten days, scrubbed clean with warm water and soft soap, and mopped dry.

This type of floor is more expensive than concrete and less expensive than tile or marble. It is used for floors of buildings where an attractive and durable floor is desired, but is inelastic and cold. The greatest objection to terrazzo floors is their tendency to crack. Dividing strips greatly reduce this objection.

Terrazzo is not used directly over a wood sub-floor. If placed over wooden construction it should have a base similar to that used for tile floors, as shown in Fig. 201*b*.

A terrazzo wall base is commonly used with terrazzo floors. It is usually made in the form of a sanitary cove base, the angle between the floor and the wall having a fillet to facilitate cleaning. A terrazzo base will not adhere to lime plaster, hardwall plaster, gypsum blocks, or plaster board. The backing should be brick, stone, concrete, hollow clay tile, or metal lath.

Magnesite Composition. A large number of magnesite composition floors are on the market. In some, the materials are furnished by the manufacturers to be laid with local labor, while in others the material and labor are furnished by the manufacturers.

In general, magnesite composition floors consist of a dry mixture of magnesium oxide, asbestos or other inert material, and a pigment to which liquid magnesium chloride is added on the job to form a plastic material which is troweled to a smooth finish and sets hard in a few hours. Magnesium chloride in the powdered form may be included with the magnesium oxide and other materials, in which case it is only necessary to add water on the job.

Magnesium oxide is obtained by calcining magnesite, which is magnesium carbonate, the carbon dioxide being driven off in the process. When magnesium chloride is added to magnesium oxide a cementing material known as magnesium oxychloride is formed. This is the cementing material in magnesite composition floorings, the asbestos being the inert aggregate. Asbestos is chosen on account of its toughness and cushioning effect.

The finished surface is usually ½ in. thick, but floors as thick as 1½ in. are used. The 1½-in. flooring is usually applied in two layers of about equal thickness. The lower layer is fibrous and serves as a cushion for the upper layer which is harder and forms the wearing surface. Magnesite flooring may be applied to a sub-floor of wood, concrete, or

steel plates. If the sub-floor is wood, a base course or foundation is required in which metal lath or wire mesh is placed to prevent cracking.

A wall base of the same material may be placed at the same time as the floor, be made monolithic with it, with a rounding corner between the two forming a sanitary base which is easily cleaned. This base should not be applied over hardwall plaster, Keene's cement, gypsum blocks, or plaster board as it will not adhere to these surfaces. It will adhere to hollow clay-tile, brick, stone, or concrete masonry and to wood or metal lath. Metal lath should preferably be galvanized.

This type of floor is less attractive and less durable than clay tile, terrazzo, and marble, but is more comfortable to work on and less noisy than these floors. It is easily cleaned and fire-resistant.

Magnesite composition is suitable for foot traffic and is appropriately used on the floors of schools and office buildings.

ARTICLE 60. CLAY TILE, BRICK, STONE, AND GLASS

General Comments. Hard materials of various kinds, including clay tile, brick, stone, and glass, are used in tile or slab form for wall surfaces and, with the exception of glass, for floor surfaces also.

Clay tile of various shapes, sizes, thicknesses, colors, and surface finishes are manufactured for use as a surfacing material for interior and exterior floors and walls where a high type of surface is desired.

Structural clay facing tile, as described in Art. 27, are manufactured for use as structural units in constructing partitions and interior and exterior wall surfaces. They are manufactured with dull and glazed exposed surfaces to provide a finished wall surface. Extruded wall ashlar, which is similar to structural clay facing tile but is more accurately finished, is available for use as a combined structural and facing wall material and for use as a surfacing material only as described in Art. 28.

Clay brick, as described in Art. 25, and special paving brick are used for floor surfaces under severe conditions. Facing brick and brick with glazed and enamel exposed surfaces are used as facing material as well as a structural material for interior and exterior surfaces of brick walls and partitions.

Various forms of natural stone, including marble, travertine, granite, sandstone, limestone, and slate, are used for interior and exterior floor and wall surfaces in the form of tile or large slabs. These materials are discussed in Art. 26.

Structural glass is available in the form of tile or slabs in thicknesses from $\frac{1}{4}$ to $1\frac{1}{4}$ in., in various opaque colors, and with polished or honed

finish, for use as a finish on exterior and interior wall surfaces. It is known by various trade names such as *Carrara Glass, Vitrolite,* and *Opalite.*

These materials may cover the entire wall surface or they may extend upward only a few feet to form a wainscot and thereby protect the portion of the wall which receives the most severe use. They are all easily cleaned.

All the more important materials, except clay tile, are described in other articles and so will not be considered further.

Clay Tile. Clay tile are usually set in portland cement mortar when used on the interior of buildings but quarry tile and promenade tile are set in asphalt over membrane waterproofing on roof gardens or in similar positions where a water-tight floor is required. Floor tile are usually set on a concrete slab foundation or base; so wood floors must be specially constructed to receive this base, as described in Art. 55 and illustrated in Fig. 201. Wall tile are set in a bed of portland cement mortar applied to masonry walls or over portland cement plaster on metal lath if applied to walls or partitions with wood studs. Recently a thin-setting bed for floor tile was developed. It consists of emulsified asphalt and portland cement and is designed for use over wood, steel, and concrete surfaces. Its small thickness of $\frac{1}{16}$ to $\frac{3}{8}$ in. makes possible the use of tile floors in locations which formerly would not have been suitable.

Clay tile are divided into many classes depending upon the processes of manufacture, the degrees of vitreousness, and other properties. These classes are considered more in detail in subsequent paragraphs. The Tile Manufacturers Association divides tile into *exterior* and *interior tile,* according to their exposure, and into *wall* and *floor tile,* according to their position. According to the Association, tile sizes in general are based on a geometric retrogression from a 6-in. square, as shown in Fig. 205, a practice inherited from medieval potters. Many sizes and shapes other than the square tile shown in the figure are manufactured. *Trimmers* are available for angles, corners, recesses, and for special uses.

Clay tile are made by burning special clays or mixtures of clays which have been pressed into the desired shape. Two processes are used: the plastic process and the dust-pressed process.

In the *plastic process,* the clays are mixed with water and run through pugging machines until a uniform plastic consistency is secured. They are then pressed by hand or machine in dies or molds and, after drying, are burned in kilns. The plastic nature of the materials has a tendency to produce tiles which are slightly irregular in shape.

In the *dust-pressed process*, the clays, after being finely ground and mixed with water, are passed into filter presses where the excess water is pressed out. The resulting mass is dried, pulverized, pressed into shape in metal dies, and burned in kilns.

The production of special sizes and shapes in the dust-pressed process involves special dies and handling, and is a deviation from the regular routine of manufacture. In the plastic process special sizes and shapes may be produced without distinct departure from the methods of production common to the regular tile.

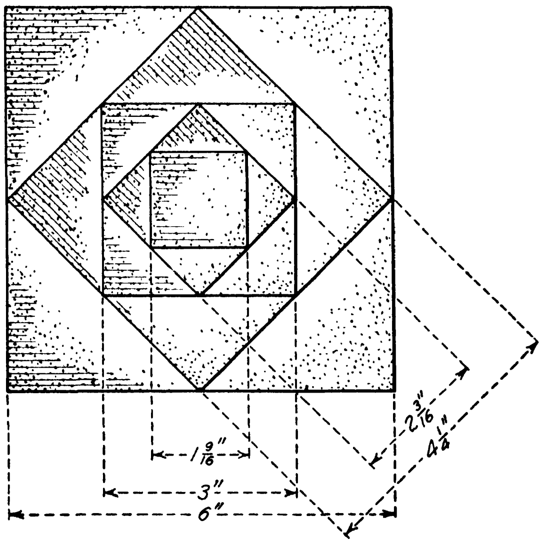


FIG. 205. Basis of Tile Sizes

Clay tile may be glazed or unglazed. For use in residences, all types of floor glazes are sufficiently durable for floors, but for public buildings subjected to severe traffic a special high-fire type of glaze is available.

The colors in unglazed tiles are produced either by the selection of clays which will burn to the desired colors, or by the addition of certain materials such as the oxides of cobalt and chromium. Some clays and color ingredients can be fired to complete vitrification, producing vitreous tile, while others will not stand this high temperature and produce semi-vitreous tile. A great variety of colors and textures are available.

Unless otherwise noted, the various types of vitreous tile are obtainable in the following colors: white, celadon, silver gray, green, blue-green, light blue, dark blue, pink, cream, and granites of these colors. The semi-vitreous tiles are available in buff, salmon, light gray, dark

gray, red, chocolate, black, and the granites of these colors. The term granite means a mottled color resembling granite.

The most common shapes of tile are square, rectangular, hexagonal, octagonal, triangular, or round; and the sizes vary from ½ in. to 12 in., and the thickness from ¼ in. to 1½ in. Trim tile are available for use as wall base or to meet any other decorative or utilitarian demands.

Various names are given to the tiles of different sizes and shapes. The more common types used for floor surfaces are the following:

Ceramic mosaic include unglazed dust-pressed tile ¼ in. thick with an area of less than 2¼ in. They are vitreous or semi-vitreous, depending on the color, and may be square, oblong, hexagonal, or round. These tile usually are mounted with exposed face stuck to paper in sheets about 2 ft. by 1 ft., the paper being removed after the tile are set. If desired the tile can be obtained loose.

Plastic mosaic include the same size and shape tile as ceramic mosaic, mounted or loose, but these tile are made by the plastic process, and the colors are those that result from the firings of natural clays.

Cut mosaic floors are made from unglazed, dust-pressed, vitreous or semi-vitreous strips, ¼ in. thick, and ½ or ⅝ in. wide, which are cut into the irregular pieces necessary in the production of ungeometric designs and pictorial work. These tile are furnished in loose strips or are assembled in designs mounted with exposed face on paper which is removed after the tile are set.

Vitreous tile and *semi-vitreous tile* are names applied to unglazed, dust-pressed tile ½ in. thick. These tile are vitreous or semi-vitreous depending on the color. They are furnished in the same shapes as ceramic mosaic, except round, but are larger, having an area of 2¼ sq. in. or greater, the largest vitreous tile being 3 in. square and the largest semi-vitreous tile, 6 in. square.

Paving tile are unglazed, dust-pressed tile ¾ in. thick. Flint tile are vitreous paving tile, and the semi-vitreous are called *hydraulic tile.* These tile may be square, oblong, hexagonal, or octagonal. With the exception of the oblong tile the smallest size is 4¼ in. and the largest 6 in. Oblong tile vary in size from 6 in. by 3 in. to 10 in. by 5 in.

Corrugated paving tile are semi-vitreous, unglazed, dust-pressed paving tile $\frac{13}{16}$ in. thick, and 6 in. square with corrugated face.

Rough red paving tile are semi-vitreous, unglazed, dust-pressed tile, ½ in. or ⅝ in. thick, depending on the size, and 6 in. or 9 in. square with the corresponding oblong half-tile.

Inlaid or *encaustic tile* are unglazed dust-pressed decorative tile, ½ in. thick, produced by inlaying a figure or ornament of one or more colors

into a body of a contrasting or harmonizing color before firing. They are vitreous or semi-vitreous according to colors.

Quarry tile are machine-made unglazed tile, $\frac{3}{4}$ in. to $1\frac{1}{2}$ in. in thickness, made from common clays. They are always square, the common size being 6 in., 9 in., and 12 in. The colors may be various shades, plain red, or the following granites: red, light gray, dark gray, black, chocolate, light brown, dark brown, or green.

Promenade tile are machine-made, unglazed tile 1 in. thick, made from common clays. The size is always 6 in. by 9 in., and the color, some shade of red.

Plastic tile are unglazed tile made by the plastic process from natural clays. Any size or shape can be obtained. The thickness is $\frac{1}{2}$ in. or over, depending upon the size.

ARTICLE 61. LINOLEUM, CORK, RUBBER, AND ASPHALT

General Comments. Elastic or resilient materials of various kinds, including linoleum, cork, rubber, and asphalt, are used for floor and wall surfaces. These materials are usually cemented to wood, concrete, or plaster surfaces with special cements.

Linoleum. Linoleum is used as a covering for wood and concrete floors. In making linoleum, linseed oil is oxidized by exposure to the air into a tough, rubber-like substance which is mixed with ground cork, wood flour, coloring matter, and other ingredients, and the resultant plastic substance is pressed upon a backing of burlap. It is then passed into drying ovens where it is thoroughly cured and seasoned. There are three common types of linoleum: plain, printed or stamped, and inlaid. Linoleum is furnished in thicknesses varying from $\frac{1}{20}$ in. to $\frac{1}{4}$ in. in rolls usually 2 yd. wide, but in some cases 4 yd. wide. It is also available in tile form.

Plain linoleum is a solid color throughout its entire thickness It is furnished in several thicknesses, varying from $\frac{1}{12}$ in. to $\frac{1}{4}$ in., and in many colors. The thicker grades are known as battleship linoleum and are the most satisfactory grades for heavy traffic.

Stamped or printed linoleum has a pattern printed on the surface with oil paint. It varies in thickness from $\frac{1}{20}$ to $\frac{1}{12}$ in. and is satisfactory for light service only, because the pattern wears off in time. After the pattern shows wear, the linoleum is still serviceable, but is unattractive. Occasional varnishing will preserve the pattern.

Inlaid linoleum consists of small units of linoleum of various colors arranged in patterns and pressed on a burlap back. The color of each unit is constant throughout the entire thickness; so the pattern remains

as long as the linoleum lasts. Inlaid linoleums are furnished in thicknesses varying from $\frac{1}{12}$ in. to $\frac{1}{8}$ in. They are used extensively and will give satisfactory service wherever their use is appropriate.

The best method of laying linoleum is to paste a layer of heavy unsaturated felt paper to the concrete or wood floor and then to cement the linoleum to the felt. Linoleum is often cemented directly to the concrete or wood floor, but with less satisfactory results than with the above method. Linoleum is sometimes tacked to wood floors. This method is very unsatisfactory.

Linoleum which is cemented directly to a matched wood floor tends to split as the boards shrink. If it is tacked around the edges and not cemented, it buckles because the traffic on linoleum tends to make it spread slightly. Matched floors should be sanded before linoleum is laid. Even if sanded, the outline of matched wood flooring eventually tends to show through linoleum, especially if the boards cup somewhat as they often do. For this reason, $\frac{5}{8}$ in. plywood is an excellent subfloor for linoleum because the joints will be 4 ft. apart and may not show at all if securely nailed. The felt paper is not required under linoleum laid on concrete, but additional cushioning effect can be secured by using this paper.

When a suitable linoleum is properly laid it will last for many years. It is sanitary, easily cleaned, resilient, warm, and attractive. Considering the length of life and satisfactory service it may be classed as an inexpensive floor covering. Linoleum should not be used in basements. A special cove wall base is available for use with linoleum, and special linoleums are available for wall coverings.

Linoleum floors are commonly used without any surface treatment but if plain and inlaid linoleums are waxed and stamped linoleums are varnished, as often as the use requires, the floors will be more easily cleaned and will last longer.

Linoleum tile are of the same composition as linoleum, and have the same properties and uses, but may be arranged in patterns to form a floor which may be more attractive than linoleum. They are cemented to a wood or concrete floor in the same manner as linoleum.

Cork. Cork flooring is available in two forms, i.e., cork carpet and cork tile. Floors of wood or concrete may be covered with *cork carpet*, which is a covering similar to linoleum, and is laid in the same way. It is composed of the same material: oxidized linseed oil, ground cork, and wood flour, pressed to a burlap back, but it is not subjected to as great pressure as linoleum, and so is more resilient and porous and less durable. Cork carpet is $\frac{1}{4}$ in. thick and is furnished in rolls 2 yd. wide. Many colors are available.

To secure the best service, cork carpet should be laid by first pasting a layer of unsaturated felt to the wood or concrete floor, and then cementing the cork carpet to the felt. Cork carpet is often cemented directly to wood or concrete, and is sometimes tacked to wood floors. The latter method is particularly unsatisfactory.

Cork carpet makes a very quiet floor covering, and is more elastic and more absorbent, but less durable, than linoleum. It is particularly suitable for use in churches, theaters, public libraries, and other places where a noiseless floor covering is essential. Cork carpet should not be used in basements where the floor and walls are not waterproofed.

Cork tile are made from pure cork shavings compressed in molds to a thickness of $\frac{1}{2}$ in., and baked. They are used over wood or cement floors to which they are cemented. Cork tile are elastic, noiseless, fairly durable, and quite absorbent. They are available in various shades of brown. The rosin in the cork liquefies during the baking process and cements the shavings together when the tile cools. The brown color of cork tile is largely due to the baking it receives, the darker browns having been baked longer than the lighter browns. Cork tile are used for wall coverings as well as for flooring.

Rubber. Rubber flooring is made of pure rubber, combined at high temperatures with fillers, such as cotton fiber, granulated cork, or asbestos fiber, and with the desired color pigments. It is made in the form of sheet rubber and rubber tile. The thickness varies from $\frac{1}{8}$ to $\frac{3}{8}$ in. Many colors and patterns are available. Rubber flooring is cemented to concrete or wood in the same manner as linoleum. It is attractive in appearance, elastic, noiseless, durable, easily cleaned, but quite expensive. Rubber floors are not resistant to oil, grease, and gasoline and should not be used on floors in contact with the ground. Rubber is used as a wall covering as well as a flooring material.

Asphalt. Asphalt floors are of three types, i.e., asphalt tile, heavy asphalt mastic, and light asphalt mastic. *Asphalt tile* are made from asphalt, asbestos fiber, mineral pigments, and inert fillers by amalgamating under heat and pressure. The sheets produced by this process are cut into tile of various sizes usually between 9 in. square and 18- by 24-in. rectangles, but smaller and larger sizes are available. The thicknesses are $\frac{1}{8}$ in., $\frac{3}{16}$ in., and $\frac{1}{4}$ in. The thinnest tile are suitable for placing on concrete when the traffic is not heavy. The most commonly used thickness for placing on wood and concrete is $\frac{3}{16}$ in., and for severe service the $\frac{1}{4}$-in. thickness is used. Asphalt tile are available in a great variety of colors varying from light to dark. Asphalt tile for industrial use are available in $\frac{1}{4}$-in., $\frac{3}{8}$-in., and $\frac{1}{2}$-in. thicknesses. They are black or mahogany in color.

When placed over a wood floor, an asphalt-saturated felt is first cemented to the wood, and the tile are then cemented to the felt. For new wood construction, manufacturers recommend that *underlayment* of plastic cement be placed on the sub-floor, instead of providing the usual wood floor, and that the tile be cemented to this base. They are cemented directly to a finished concrete floor, but, if the floor is a rough slab, the roughness and unevenness are overcome with an underlayment.

Asphalt tile are resilient, non-absorbent, reasonably stainproof and acidproof, relatively inexpensive, attractive, and moistureproof so that they can be used on concrete floors below the ground level. They are not resistant to grease and oil, but special "greaseproof" tile are available. They are suitable for use in schools, apartment and office buildings, hospitals, laboratories, residences, and many other kinds of structures. Asphalt tile are used as a wall covering as well as a flooring material.

The term *asphalt mastic* is applied to two classes of floors which are very different in composition, properties, and use. In both the cementing material is asphalt, but in one it is mixed hot with sand or crushed rock and laid hot in a continuous sheet 1 to 2 in. thick, or pressed into blocks. In the other it is fluxed with a mineral oil, mixed with asbestos, and applied cold with a trowel in four or five coats, building up to a total thickness of $\frac{1}{8}$ to $\frac{1}{4}$ in. The first is used in industrial buildings, and will withstand heavy traffic; whereas the second is used in office buildings, schools, etc., and is suitable only for foot traffic.

The *heavy asphalt mastic* floors consist of natural asphalt, crushed rock, and a fine aggregate of sand or crushed-rock screenings. They may be placed in a sheet or in blocks. Sheet-asphalt floors are mixed and placed at a temperature of about 300 deg. fahr. and are rolled to form a compact layer with an even surface. They may be as thin as 1 in. for foot traffic only, but should be $1\frac{1}{2}$ to 2 in. thick for heavy traffic. The base may be either wood or concrete. If the base is of wood, a layer of building paper is placed on the base before the asphalt is placed. Asphalt mastic blocks are made at the factory and shipped to the building. In making these blocks they are subjected to a very heavy pressure. The blocks are 4 or 5 in. wide; 8 or 12 in. long; and $1\frac{1}{4}$, 2, and $2\frac{1}{2}$ in. thick. If laid on a concrete base the blocks are set in cement mortar. The joints are filled with fine sand, hot liquid asphalt, or grout.

These heavy asphalt mastic floors are elastic, dustless, durable, and waterproof and acidproof. They are used in factories, warehouses, loading platforms, dampproof cellars, swimming pools, hotel kitchens, etc., and on floor surfaces which are outdoors.

Light asphalt mastic flooring is composed of asphalt, for a cementing material, fluxed with mineral oil and mixed with an inert material, usually asbestos fiber and a pigment. It is usually placed cold in four or five coats with a trowel over a concrete or wood base, and has a total thickness of $\frac{1}{8}$ to $\frac{1}{4}$ in. The thin coats are used so that each coat may dry out and harden before the next is placed. The common colors are green, red, brown, and black. A sanitary cove wall base may be made monolithic with the floor surface, but it is first necessary to provide a foundation, which, when the thin layer of mastic is applied, will give a base of the desired shape.

Light asphalt mastic resembles linoleum in its appearance and in some of its properties, but it is less absorbent and more acidproof. It is warm and comfortable to work on and is easily cleaned. This type of flooring is used in office buildings, hospitals, schools, bathrooms, damp cellars, etc., and may also be used outdoors on the floors for roof gardens and porches. It is not suitable for use where it will be subjected to the action of oil and grease, and will not withstand heavy trucking.

Light asphalt mastic flooring is also manufactured in sheets $\frac{1}{8}$, $\frac{3}{16}$, and $\frac{1}{4}$ in. thick, ready for placing. These sheets have the same composition and use as the material just described, but have the advantage of ease in placing. The joints are made with the same material in plastic state, and repairs are also made with this material.

ARTICLE 62. PLYWOOD, WALL BOARD, AND OTHER BOARDS

Many types of wall boards are available in a great variety of forms to use as finished surfaces for interior walls and ceilings. Some are the cheapest form of finish which can be provided and others compare with clay wall tile in cost. They are usually furnished in large sheets 4 ft. wide and up to 12 ft. in lengths. Wide boards can be obtained on special order.

Plywood. Plywood consists of thin layers or *plies* of wood glued and pressed together, with the grain direction of adjacent plies at right angles to each other, to form large rigid panels commonly from $\frac{3}{16}$ in. to $1\frac{3}{16}$ in. thick with widths up to 4 ft. and lengths up to 8 and 10 ft. The number of plies is 3, 5, or 7, the odd number being necessary to avoid warping. The outside plies are called *faces* or *face* and *back*. The intermediate plies with grain parallel to the grain of the faces are called *cores*, and those with grain at right angles to that of the faces are called *crossbands*. The plies are made by softening logs, steaming, and placing them in lathes which are arranged with a cutter to slice

off, or *rotary-cut* sheets of veneer in a manner similar to unrolling paper. Douglas fir plywood is available in the *moisture-resistant type,* the *exterior type,* and the *highly moisture-resistant type,* depending upon the moisture resistance of the glue used.

Plywood is made from many different species of wood, the most common being Douglas fir. Plywood is available with faces of Douglas fir, gum, birch, red and white oak, Philippine mahogany, African mahogany, black walnut, and many other woods.

The faces of plywood may be *good,* which means practically clear, all-heart veneer; the faces may be *sound,* having neatly made patches, sapwood, and stain, but must be smooth and suitable for painting or natural finish; or the faces may be classed as *utility,* and contain knots, splits, pitch pockets, etc., which will not interfere with the use of the panels. A sheet may have two *good* faces, designated G2S; one *good* face and one *sound* face, G1S; or two *sound* faces, S2S.

Moisture-resistant Douglas fir plywood is furnished in *standard panels,* which are used primarily for natural finish and are sanded on both faces; *wallboard,* which is the most widely used plywood product, the principal uses being for facing interior walls and ceilings, and both surfaces being sanded; and *sheathing,* which is an unsanded utility grade for wall and roof sheathing, sub-flooring, and miscellaneous construction purposes.

Plywood with a highly water-resistant glue is used for concrete forms which can be reused 10 to 15 times.

Exterior plywood is made by the hot-pressed synthetic-resin-bonded process and is intended for permanent exterior use. It is generally considered as having a waterproof, rather than water-resistant, glue bond. It is used for outside paneling and siding of buildings.

Some of the thicker plywoods are available, with a lumber core rather than the thin plies, for use as cupboard doors, table tops, counter fronts, etc. Either the separate veneers themselves or two-ply panels $\frac{1}{8}$ in. thick can be furnished for bending to form curved surfaces.

For decorative effects, the surface of plywood may be finished natural, stained, or painted. Wall paper may be applied to plywood over building felt or muslin.

Various moldings are available for covering the joints of interior plywood, or a V-joint can be made by beveling the edges.

Some of the advantages of plywood are the large sizes available; its freedom from warping, shrinking, or cracking; and the availability of decorative hardwood faces at relatively low cost.

Fiber Boards. Fiber boards are made from masses of cane or wood fibers by pressing them into sheets or boards with thicknesses from

$\frac{1}{4}$ in. to 1 in. or more. The usual widths are 4 ft., and lengths up to 12 ft. are available. The fibers may be rather loosely compressed to give good heat-insulating and sound-absorbing properties. The surface is usually fibrous, but boards are available veneered with walnut, mahogany, or other woods. Others have an imitation wood finish. Some boards are divided into tile or given other surface design by bevel scoring. Strips called *planks* are made 6 in. to 16 in. wide and up to 12 ft. long. Sheets are cut into individual tile of many sizes, with a variety of colors. The large unfinished sheets are called *building boards*. Fiber boards are used for exposed interior wall and ceiling surfaces, for outside wall sheathing and for heat insulation and sound absorption. They may be obtained coated with asphalt as a vapor seal. Boards of any thickness are made by cementing thinner boards together with asphalt cement. Some boards have an aluminum-coated back to serve as reflective insulation. See Arts. 76 and 77.

Hard Boards. This product, which is known under the trade names of *Pressedwood* and *Prestwood*, is made by subjecting masses of specially treated and separated wood fibers to heat and very high pressures to form a dense, hard, impervious board, no other material being added. *Tempered board* is made by further treatment with liquids and heat. The sheets are 4 ft. wide and up to 8 ft. long with thicknesses of from $\frac{1}{16}$ in. to $\frac{5}{16}$ in. A great variety of colors are available including the natural light brown, black, imitations of walnut, mahogany, and other woods, and various marbles. Special finishes are formed on the tempered board for decorative effect and to seal the pores and increase the resistance to acids, alkalies, alcohol, and other stains. The various forms of this material are used for wall surfaces, wainscots, table tops, and counter tops.

Plaster Boards. Plaster boards or gypsum wall boards are sheets of gypsum molded between heavy paper. It is made in thicknesses of $\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{2}$ in., with widths of 32, 36, and 48 in. and lengths up to 12 ft. If the surface is to be exposed, the joints may be covered with wood panel strips to form panels or covered with fabric glued over the joints and covered with a thin coating of special cement. Some boards are depressed along the joints so that the joints can be concealed by buttering with cement and covering with fabric. The surface of the board may be painted. Plaster boards are available with a finished surface grained to imitate various woods such as walnut, mahogany or knotty pine. The grain is printed on the paper covering and is said to be reproduced from actual woods. These boards are lacquered and require no further finishing. They are usually used for panels with the joints covered with wood strips. Boards are on the market, divided

into 4-in. square tile by surface indentation. They are finished with a varnish priming coat and then painted or enameled. Actual veneers of walnut, mahogany, and other woods are applied to gypsum board. These are shipped in the natural wood to be finished on the job.

Asbestos-Cement Board. This type of board is made from asbestos fiber and portland cement molded under pressure to form a dense hard-surfaced sheet usually $\frac{1}{8}$, $\frac{3}{16}$, and $\frac{1}{4}$ in. thick, 4 ft. wide, and in lengths up to 8 ft. The exposed surface is finished smooth. One type is made in the natural cement color and other decorative colors which extend through the sheet. The sheets may be plain or scored to resemble tile 4 in. square. Other boards are available with various baked-on colored and marbleïzed surface finishes divided into tile. The tile joints may be cut with a narrow abrasive wheel or be molded. The joints and edges are usually covered with specially designed chromium or stainless steel moldings. The sheets can be cut with a wood saw, and other operations can be performed with woodworking tools.

Plastic Veneers. Plastics that are impervious, hard, non-breakable, durable, and attractive are applied as veneers to plywood, Prestwood, and asbestos-cement board to form sheets as large as 4 by 8 ft. The veneer is available separately in sheets $\frac{1}{16}$ in. thick. The asbestos-cement board sheets are recommended for exterior use. A great variety of plain colors and wood and marble imitations are available. The veneer is very resistant to acids, alkalies, and alcohol and can be easily cleaned. Special grades which are cigaretteproof are available. This material is used for wall surfaces, wainscoting, counter tops, table tops, and in many other locations. Various methods of fastening the sheets without exposing nail heads have been devised.

ARTICLE 63. SELECTION OF WEARING SURFACE FOR FLOORS

The selection of a proper floor surface is one of the most important and, at the same time, one of the most difficult problems which arise in the construction of a building. The appearance, usefulness, and cost of upkeep of a building are greatly affected by the type of floor which is installed. Considering the importance of the subject, it is unfortunate that it is not possible to devise a satisfactory basis of selection.

The Report of the Committee on Floors of the American Hospital Association has been of considerable value in preparing this article. The definitions of the properties of floor surfaces follow those of the Committee quite closely.

The following discussion of the relative merits of the various floor surfaces is prepared, realizing that the value of such discussion is

limited because of the great variations in the materials and workmanship, and in the kind of usage and care a floor will receive.

Floors which are manufactured complete and ready for installation, such as tile, linoleum, and rubber, will show less variation in quality than such floors as terrazzo, concrete, and magnesite composition which are manufactured on the job, and are not subject to as rigid control as factory-made products. Natural flooring materials such as marble and slate are also quite variable in quality.

Each property of a wearing surface will be discussed and an attempt will be made to classify roughly the various materials according to the degree to which they possess that quality.

Appearance. Appearance is the attractiveness of the material, its color range, texture, and its decorative value in an architectural sense.

There are many floor surfaces which are attractive when suitably used, such as hardwood when properly finished, terrazzo, clay tile, marble, and, to a less degree, rubber tile, cork tile, linoleum tile, asphalt tile, linoleum, cork carpet, sheet rubber, slate, and composition. Concrete without special treatment, heavy asphalt mastic, and industrial wood blocks are not suitable for use where appearance is a factor. Concrete floors may be painted or waxed, and are not unattractive as long as the surface is maintained, but this is difficult to do where the traffic is at all heavy.

Durability. Durability may be defined as the resistance to wear, temperature, humidity changes, decay, and disintegration. The adhesion of a material to its base is also a factor in durability.

The most durable floor surfaces for foot traffic are clay tile, terrazzo, slate, and concrete, but terrazzo floors are very likely to crack if not divided into blocks by dividing strips or laid in the form of tile. Marble is widely used in floors subject to severe wear, but it does not stand up as well as the materials just mentioned. Some marbles are much more resistant to wear than others. Concrete surfaces to be durable must have durable aggregates.

Hardwood, linoleum, linoleum tile, and rubber tile give very satisfactory service; whereas cork carpet, cork tile, asphalt tile, magnesite composition, and light asphalt mastic are fairly satisfactory.

With the exception of concrete, none of the materials mentioned so far is suitable or satisfactory for heavy traffic. Brick, wood blocks, and heavy asphalt mastic may be used under these conditions. Heavy maple flooring may also be satisfactory.

Comfort. Comfort under foot is determined by the shock-absorbing qualities, sure-footedness, evenness of surface, and conductivity. A floor which is a good heat conductor will always feel cold.

The most comfortable floors to work on are cork tile, cork carpet, and rubber. Wood, linoleum, magnesite composition, asphalt tile, and light or heavy asphalt mastic are very satisfactory, but concrete, terrazzo, clay tile, marble, slate, and brick are tiresome and cold.

Noiselessness. Cork tile, cork carpet, and rubber are practically noiseless; wood, linoleum, magnesite composition, asphalt tile, and asphalt mastic are somewhat less satisfactory but still very good; but concrete, clay tile, marble, slate, and brick are the noisiest of flooring materials.

Fire Resistance. Materials may be non-combustible but still suffer severely in case of fire.

Concrete, clay tile, and brick are probably the most fire-resistant floor surfaces, but terrazzo, marble, and slate should be very satisfactory. Magnesite composition, asphalt tile, and asphalt mastic will not burn, but may suffer seriously in a fire. Linoleum, cork carpet, rubber and wood are combustible, but if laid on a fireproof base they are not considered a serious defect in a fireproof building.

Sanitation. To be sanitary, a floor surface must be non-absorbent and easily cleaned. Joints which are not water-tight are an unsanitary feature.

The most sanitary floor surfaces are terrazzo, clay tile, marble, and slate. Magnesite composition, asphalt tile, asphalt mastic, rubber, and linoleum are quite satisfactory. Cork carpet is unsatisfactory on account of its porosity, concrete on account of the difficulty in cleaning, and wood on account of its porosity and the presence of open joints.

Acid and Alkali Resistance. The factors which should be considered under this heading are immunity from damage by occasional spillings of strong acid solutions and resistance to the continuous use of soap, lye, cleaning and scouring compounds, and disinfectants.

Clay tile is the most satisfactory floor surface in this respect; heavy and light asphalt mastic and asphalt tile are quite resistant; rubber, terrazzo, marble, concrete, and magnesite composition are sufficiently resistant for ordinary purposes; but linoleum, cork carpet, and cork tile should not be subjected to the action of acids and alkalies.

Grease and Oil Resistance. Grease and oil are not absorbed by clay tile and do not affect this material. They are absorbed by wood, brick, concrete, terrazzo, linoleum, cork carpet, and cork tile, and therefore detract from their appearance, but they do not seriously affect their durability. All forms of asphalt and rubber floors are seriously affected by grease, oil, and gasoline except one form of greaseproof asphalt tile.

Dampness. Clay tile, brick, concrete, terrazzo, and asphalt tile are not affected by dampness and are suitable for use on floors located below grade such as basement floors; but wood, rubber, linoleum, cork carpet, and cork tile are not suitable for use in such locations.

Indentation. The hard flooring materials, such as clay tile, concrete, terrazzo, and brick do not suffer indentation from chair legs, heels of shoes, and other objects which rest on them or strike them. Maple and oak flooring yield very little and do not retain imprints. Other materials such as linoleum and rubber yield considerably under such loads but recover quite well when the load is removed. Asphalt tile and, to a greater extent, light and heavy asphalt mastic may become permanently indented.

Trucking. Three factors are pertinent when considering the suitability of a floor for trucking. It must stand the abrasive action of the truck wheels, the tractive effort required to pull the truck must not be excessive and the flooring must have structural resistance sufficient to carry the load transmitted to it by the truck wheels. Concrete, heavy maple flooring, and industrial wood blocks are satisfactory in all three respects if the materials are of high quality and if the trucking is parallel to the length of the maple flooring rather than crosswise. The maple flooring must be heavy enough so that the weight of the trucks will not break the tongue-and-groove joint. The aggregate in the concrete may have to be specially selected so as to have a high resistance to abrasion. Asphalt mastic flooring does not stand up well under trucking and considerable effort is required to pull trucks over such floors. Rubber-tired wheels are much easier on all types of flooring than wheels which are steel-tired.

Maintenance. This heading includes such items as the ease with which a flooring is cleaned, the necessity for care and surface treatment, such as waxing and painting, the necessity for repairs, and the cost of such operations.

Tile, marble, terrazzo, slate, and rubber tile floors are easily cleaned and require very little care. Linoleum, asphalt tile, and magnesite composition are easily cleaned, but should receive surface treatment occasionally. Cork carpet is not easy to clean, and requires surface treatment. Hardwood floors are fairly easy to clean if in good condition, but require frequent surface treatment. Concrete is not as easy to clean as tile, linoleum, etc., if it is not painted or waxed. Painting makes cleaning easier, but requires frequent renewal. Light asphalt mastic is easily cleaned, and requires no surface treatment.

The monolithic floors such as terrazzo, magnesite composition, and concrete are difficult to repair satisfactorily. Floors composed of sepa-

rate units of tile, slate, or marble are more easily repaired, but require skilled mechanics. Linoleum, cork tile, and cork carpet may be easily repaired by replacing the damaged parts. Light asphalt mastic can be easily repaired by patching.

The maintenance costs of wood block, heavy asphalt mastic, brick, and concrete are relatively low except under extremely severe traffic. With the exception of concrete these materials are easily repaired. They receive no surface treatment.

Initial Cost. One of the first factors which must be considered in selecting a floor surface is the initial cost, but even the most expensive materials do not possess all the features which are considered desirable.

Flooring materials may be roughly divided into classes according to their cost in place. In the following list the most expensive materials are given first:

a. Clay tile, marble, and rubber tile.
b. Terrazzo, magnesite composition, cork tile, and hardwood.
c. Cork carpet, linoleum, asphalt tile, light and asphalt mastic, and slate.
d. Concrete.

This list assumes that a concrete base is available to receive the wearing surface.

If the wearing surface is to be applied to wood floor construction the order would be somewhat changed, for a concrete base would usually be provided for clay tile, marble, terrazzo, slate, and concrete, whereas the other materials may be applied directly to the wood. In this case, the relative costs would be somewhat as follows:

a. Clay tile, marble.
b. Terrazzo.
c. Rubber tile.
d. Magnesite composition, and cork tile.
e. Cork carpet, linoleum, asphalt tile, light asphalt mastic.
f. Hardwood.

Brick, wood block, and heavy asphalt mastic floors are not included in these lists, for they are used for a different class of traffic from that to which the materials included (except concrete) are subjected; so a comparison would be of no value.

Weight. The heavier floor surfaces add indirectly to the cost by requiring stronger floor construction, beams, girders, columns, and foundations. Clay tile, marble, and slate are bedded on $\frac{1}{2}$ in. or more of cement mortar which has no structural value; terrazzo requires $1\frac{1}{4}$ in.

of material which is simply a dead weight; and hardwood flooring usually requires about 2 in. of filling between the nailing strips. Rubber tile, magnesite composition, cork tile, cork carpet, linoleum, asphalt tile, light asphalt mastic, and concrete do not require this additional material. This additional weight exists when the structural floor is some form of concrete slab, but may not be a factor in hollow-tile arch construction where a certain amount of filling is necessary regardless of the wearing surface.

REFERENCES

1. "Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete," Joint Report of a Committee Comprising Representatives of the American Society of Civil Engineers, American Society for Testing Materials, Portland Cement Association, American Concrete Institute, American Railway Engineering Association, and the American Institute of Architects, 1940.

2. "Sweet's Catalog File," F. W. Dodge Corporation.

3. LONGSHORE, JAMES H.: "Floor Research," Continental College of Floor Engineering, 1937.

4. SPURLING, O. C.: "Experience with Industrial Flooring," *Engineering News-Record,* Aug. 18, 1932.

5. SIGLER, PERCY A., and ELMER A. KOERNER: "Performance Test of Floor Coverings for Use in Low-Cost Housing," Part I, Report BMS34; and Part II, Report BMS43, National Bureau of Standards, 1940.

6. NORRIS, C. B.: "Technique of Plywood," I. Flaucks, Inc., 1942.

7. PERRY, T. D.: "Modern Plywood," Pitman Publishing Co., 1942.

CHAPTER X

ROOF CONSTRUCTION AND ROOFING MATERIALS

ARTICLE 64. TYPES OF ROOFS

Roofs of buildings are divided into various types, depending upon the shape.

Flat roofs, shown in Fig. 206*a*, are extensively used on all kinds of buildings. They are sloped from ½ in. to 1 in. vertical to 12 in. horizontal to insure proper drainage. Some designers make roofs without any slope whatever considering that water-tight roofs can be secured without any slope and the construction is simplified.

Roofs which slope in one direction only, as shown in Fig. 206*b*, are called *shed roofs*. This type of roof is used on temporary structures where appearance is not considered, where the roof can not be seen, or in connection with other types shown in Fig. 206*c* to form a *lean-to*.

Gable roofs slope in two directions, as shown in Fig. 206*d*. This type of roof is widely used, especially on residences. The slope is often as flat as 4 in. vertical to 12 in. horizontal, and as steep as 20 in. vertical to 12 in. horizontal, but the most common slopes are between 6 in. vertical to 12 in. horizontal, and 12 in. vertical to 12 in. horizontal.

Hip roofs slope in four directions as shown in Fig. 206*e*. This type of roof is widely used. The same slopes are used on hip roofs as on gable roofs.

Gambrel roofs slope in two directions, but there is a break in the slope on each side, as shown in Fig. 206*f*. The gambrel roof is used for residences on account of the efficient use which can be made of the space under the roof, especially when a long shed dormer, as shown in Fig. 207*a*, is used. *Mansard roofs* slope in four directions, but there is a break in each slope as shown in Fig. 206*g*. *Deck roofs* slope in four directions, but have a deck at the top, as shown in Fig. 206*h*.

The various types of roof dormers are shown in Fig. 207*a*.

The *saw-tooth roofs* shown in Fig. 207*b* and 207*c* are used quite extensively on industrial buildings on account of the advantages they offer in light and ventilation. The steep face of Fig. 207*b* and the vertical face of Fig. 207*c* are mostly glass and are usually turned towards the north, the light from that direction being more nearly constant

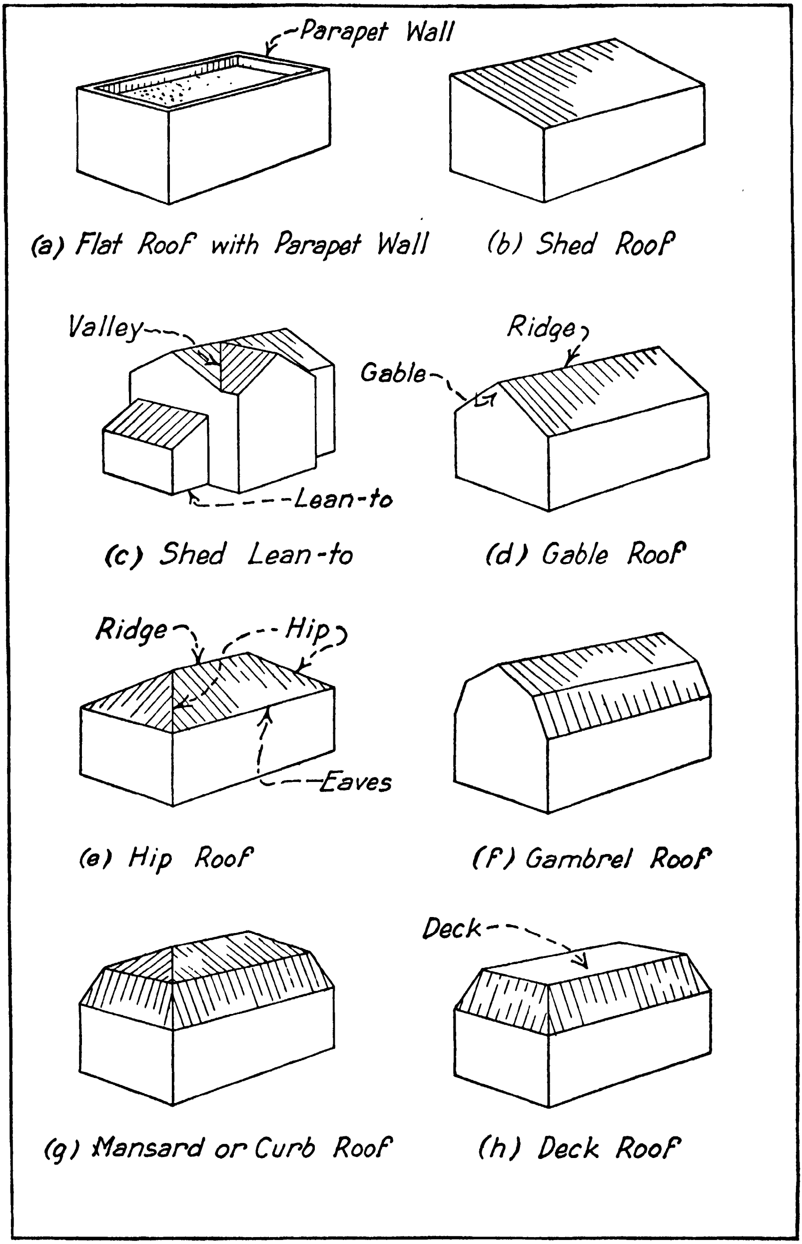


FIG. 206. Types of Roofs

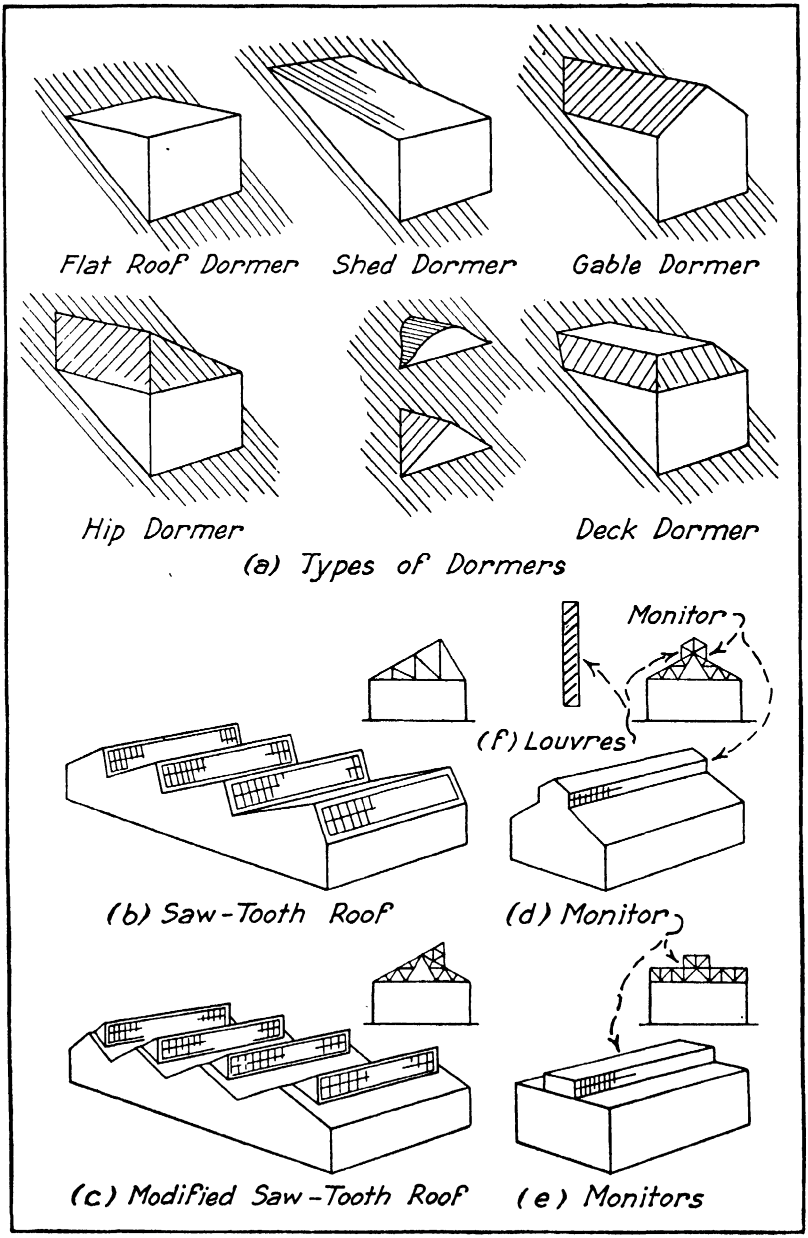


FIG. 207. Types of Dormers and Roofs

throughout the day than light from other directions and the glare of direct sunlight is avoided. The type shown in Fig. 207*c* does not have as large an area of glass as that shown in Fig. 207*b* but is more easily made water-tight in the valley. At least a part of the windows are arranged to open for ventilation. This is commonly the upper half.

The parts of a roof such as *ridge, hip, valley, gable,* and *eaves* are indicated in Fig. 207*a* to *h*. *Monitors,* as shown in Fig. 207*d* and *e*, are used extensively to secure better light or ventilation. The vertical face is called the *clerestory*. If ventilation only is desired, *louvres* (or louvers) may be used in the clerestory as shown in Fig. 207*f*.

ARTICLE 65. ROOF CONSTRUCTION

Types of Roof Deck. Nearly all forms of roof covering should have continuous surfaces to support them. Included in this group are shingles of various materials, nearly all forms of tile, slate, sheet metal, built-up roofings, such as tar and gravel, and prepared roofings. Wood shingles, tile, and slate can be laid on widely spaced sheathing or on narrow slats, one slat being required for each row of shingles, tile, or slate.

In damp climates, the use of slats to support wood shingles may be desirable because the shingles can then dry out from the under side and do not decay or tend to cup and crack as badly as on solid decks. These advantages may be more than offset by the decreased fire resistance and increased heat loss. In general, the solid deck is to be preferred, especially in the case of tile and slate where roofers' felt is used under the tile or slate to provide against leaks due to breakage or from other causes.

Corrugated sheets of steel, zinc, asbestos board, or glass will span distances of 4 or 5 ft. between purlins, and do not require sheathing. Some forms of cement tile are designed to rest directly on purlins spaced 4 or 5 ft. apart.

The solid roof deck supporting the roof covering may be of the following types of construction:

a. Wood sheathing 1 in. thick, supported on rafters for sloping roofs or joists for flat roofs spaced 12 or 16 in. apart, and usually of 2-in. material, as shown in Figs. 115, 116, 133, 134, 135, 136, and 208*a*. This sheathing may have square edges or may be matched or shiplapped.

b. Heavy wood sheathing from 2 to 6 in. thick supported on purlins for sloping roofs or on roof beams for flat roofs, spaced from 4 to 12 ft. or more apart, as shown in Figs. 137 to 139. The sheathing may be matched or may have a loose tongue or be laminated, as shown in Fig. 201*f*, *g*, and *h*.

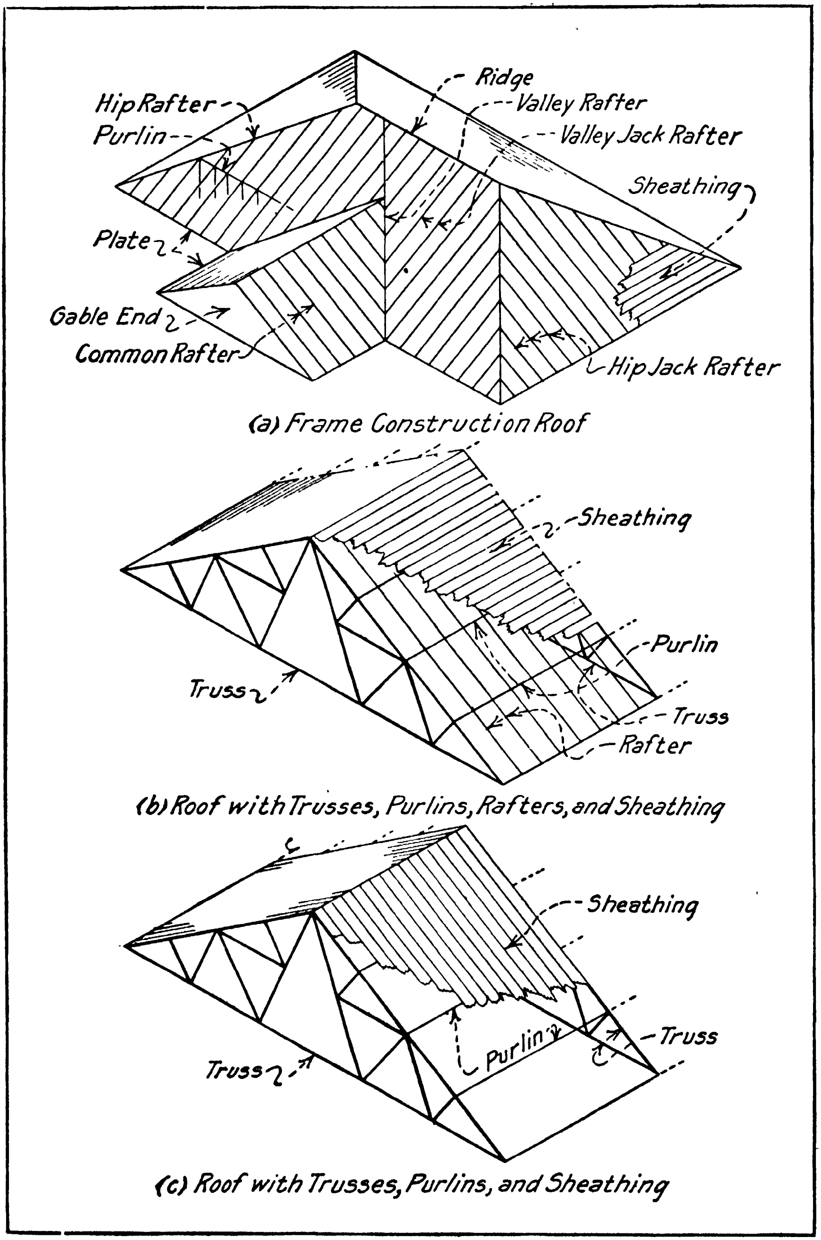


FIG. 208. Roof Framing

c. *Reinforced-concrete solid* or *ribbed slabs* supported on steel or reinforced-concrete beams as shown in Figs. 183*b* and *c*, 187*a* to *f*, 188*a* to *c*, 190, 199, and 202.

d. *Cast-in-place gypsum slabs* supported on steel beams as shown in Fig. 209*a*.

e. *Precast gypsum slabs* as shown in Fig. 209*b*, *c*, and *d*. The solid and hollow slabs are 12 in. wide and 30 in. long. They are supported on steel rafters consisting of inverted T sections, spaced 30¾ in. center to center. The rafters are supported by purlins spaced from 5 to 8 ft. apart, depending upon the size of the rafter and the load on the roof. The channel slabs are supported directly on purlins spaced up to 6½ ft. apart. Metal clips are provided to anchor the slabs to the rafters or purlins.

f. *Precast slabs* 2 ft. wide, 1½ to 2 in. thick, made of light-weight concrete designed to be supported on steel beams spaced not over 5 ft. apart.

g. *Precast cement slabs* with channel-shaped sections, similar to Fig. 209*d*, 18 in. wide, and 3½ or 4 in. deep designed to be supported on steel beams not over 10 ft. apart.

h. *Sheet-steel decks* with ribs formed on the lower side to give strength and rigidity, supported by steel or wood beams or purlins, spaced up to 10 ft. apart, to which they are fastened by clips. If a sheet-steel deck is used on a building which is to be heated in winter or which must not be excessively warm in the summer, insulation must be used. This consists of a rigid fiber board or cork cemented on the deck with hot asphalt or tar. The insulation may be bolted to the deck on steep slopes.

Heat Insulation. It is desirable to insulate the roof or the ceiling of the top story of all buildings. This reduces the heat losses and the condensation of moisture on the ceilings. The various materials on the market are described in Art. 76.

Roof Drainage. Roofs may be made flat with no slope whatever; they may be provided with a slight slope of ½ in. or 1 in. to the foot, or they may have considerable slope. Many engineers and architects advocate the absolutely flat or *dead-level roofs* because of the simplicity of construction, maintaining that the water which may stand for short periods on a roof, owing to slight irregularities, does not harm and may actually protect the roof from the effects of the sun. The type of roofing used on dead-level roofs is a built-up roofing consisting of coal tar pitch and tarred felt with a wearing surface of gravel or slag.

The slopes required for various types of roofing are discussed in Arts. 66 to 72. The rainwater which falls on a roof may be allowed to run off and drip from projecting eaves, but usually it is necessary or desir-

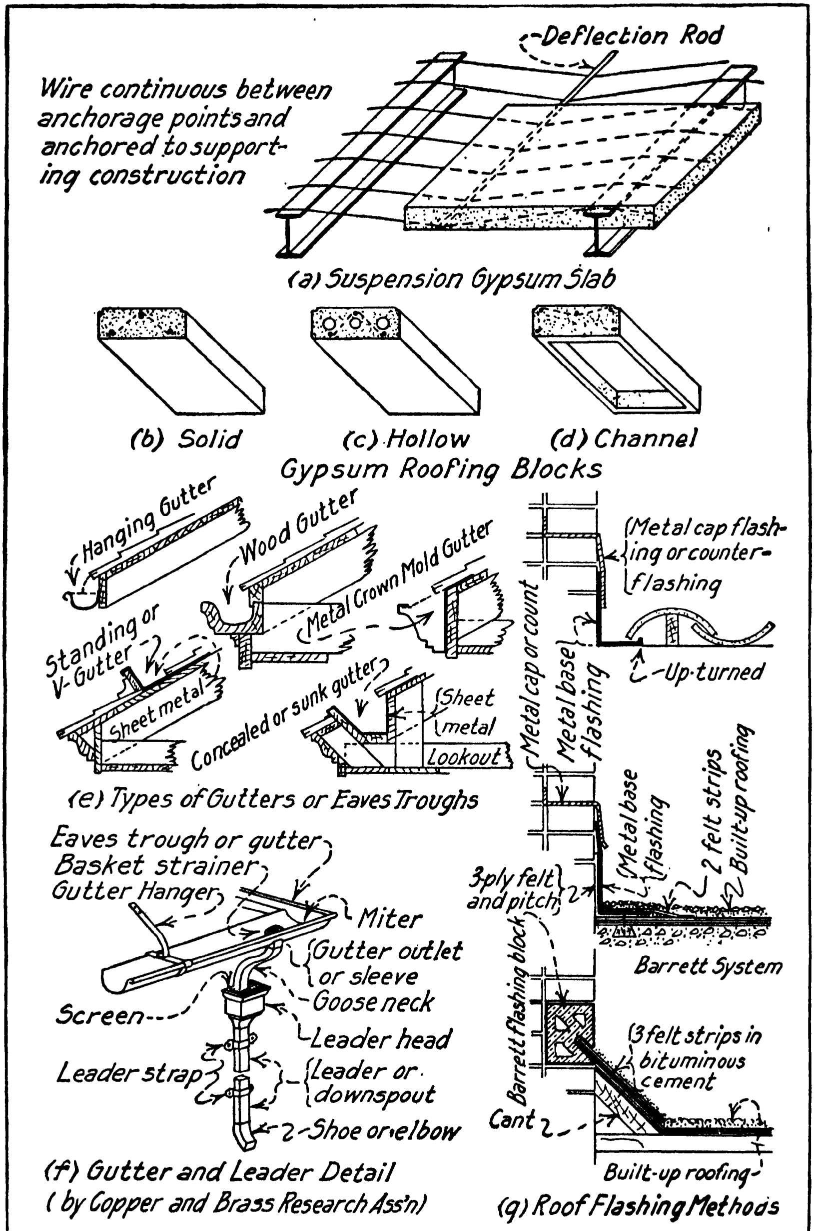


FIG. 209. Roof Construction and Drainage

able to collect the water in *gutters* placed along the eaves of sloping roofs, the water in the gutters being carried off by vertical pipes called *downspouts*, *conductors*, or *leaders*. Flat roofs or other roofs which do not have projecting eaves are drained by means of downspouts or conductors placed at points where the water is carried by the slight slope provided in the roof. The size of the gutters and conductors is determined by the contributing area and by the intensity of rainfall.

Several types of gutters for sloping roofs are shown in Fig. 209*e*. The *hanging gutter* is the simplest form, but is not as attractive as the *crown-mold gutter* or the *wood gutter* which fit into the design of the cornice. The *standing gutter* is inconspicuous and easily constructed, but the *concealed gutter* is quite expensive. Gutters are sometimes called *eaves troughs*. Cornices which are enclosed so that the rafters do not show are called *box cornices* and those in which the rafters are exposed are called *open cornices*.

Conductors or downspouts should be provided with strainers at their upper ends, as shown in Fig. 209*h*, so that leaves, sticks, and other debris can not clog them. *Conductor* or *leader heads* are used as shown in Fig. 209*f*. It is desirable to run conductors down inside of a building rather than to place them on the outside walls as the heat of the building keeps them from freezing. They may be placed in chases in the outside walls, along columns, or in partitions. If they must be placed on the outside of outside walls, it is desirable to keep them off of north walls if possible. Steam outlets are frequently provided in exposed conductors so that, by discharging steam into them, they can be kept from freezing. Cleanouts should be provided so that clogged conductors and the connecting drains can be easily cleaned. Exposed conductors are commonly made of copper and galvanized steel, and copper, cast-iron, and steel pipe are used for concealed conductors or where appearance is not a factor.

Where a roof surface meets a vertical wall, it is necessary to provide *flashing* to make the joint water-tight. Flashing usually consists of strips of some sheet metal such as copper or galvanized iron which is made L-shaped so as to fit over the joint as shown in Fig. 209*g*, one leg of the L running up the wall and the other along the roof. Rainwater which is driven against the vertical face of the wall is kept from running down behind the vertical leg of the flashing by *counter-flashing* or *cap flashing*, also made in the form of an L. The L is inverted, the horizontal leg being built or fitted into a mortar joint and the vertical leg fitting over the flashing, as shown in Fig. 209*g*. Built-up roofing is commonly flashed, as shown in Fig. 209*g*, without the use of sheet metal. To avoid the sharp corner between the wall and the roof, *cant*

strips or *boards* or concrete cants are commonly used. *Flashing blocks*, as shown in the figure, are frequently used. The angle between the back side of a chimney, or other projection, and a sloping roof is usually protected with a *saddle* or *cricket* which consists of two sloping surfaces meeting in a horizontal ridge perpendicular to the chimney. The valleys on sloping roofs are made water-tight by sheet-metal strips bent to fit the two intersecting roof surfaces. Roll roofing is often used for valleys on asphalt-shingle roofs.

ARTICLE 66. SHINGLES

Wood Shingles. The best wood shingles are made of cypress, cedar, and redwood. Standard lengths are 16, 18, and 24 in. Shingles are tapered in thickness, the thickness at the *butt* or thick end being expressed in terms of the number of shingles required to produce a total butt thickness of a designated number of inches. Sixteen-in. shingles are usually 5 butts in 2 in.; 18-in. shingles, 5 butts in $2\frac{1}{4}$ in.; and 24-in. shingles, 4 butts in 2 in.; called $5/2$, $5/2\frac{1}{4}$, and $4/2$, respectively. Regular shingles are variable in width, the maximum width permitted by grading rules being 14 in. and the minimum width 3 in. for 16- and 18-in. shingles, and 4 in. for 24-in. shingles. *Dimension shingles* are cut to specified widths. They are rarely used.

Not more than one-third of the length of a shingle should be exposed *to the weather* when used on roofs, and not more than one-half when laid on side walls. Heartwood is more resistant to decay than sapwood; edge-grain shingles are less apt to warp or cup than flat-grain shingles. Thick shingles warp less than thin shingles, and narrow shingles less than wide shingles. Shingles should be clear, entirely heartwood, and entirely edge grain. It is not economical to use anything but the best grade of shingle except for temporary construction.

Shingles should be fastened with hot-dipped, zinc-coated, iron cut nails or hot-dipped, zinc-coated, steel-and-copper nails varying in size from 3d to 4d, depending on the thickness of the shingle.

Wood shingles are nailed to wood sheathing or slats, each row of shingles being lapped over the row below, to give an exposed surface, varying from 4 to 7 in., the smaller distance to the weather being used for short shingles on flat slopes and the greater distance for long shingles on steep slopes.

The sheathing may have square edges, as shown in Fig. 210*a*; it may be matched, as shown in Fig. 210*b*; or it may be shiplapped, as shown in Fig. 210*c*. The use of wood slats is illustrated in Fig. 210*d*.

When the sheathing is without spaces between the boards, or when matched sheathing or shiplap is used, a layer of waterproof paper is

sometimes placed between the sheathing and the shingles. This paper makes the roof more air- and water-tight, but where there is heavy rainfall it will reduce the life of the shingles by making it impossible for them to dry out from the under side and thus cause rotting. In general, its use is objectionable.

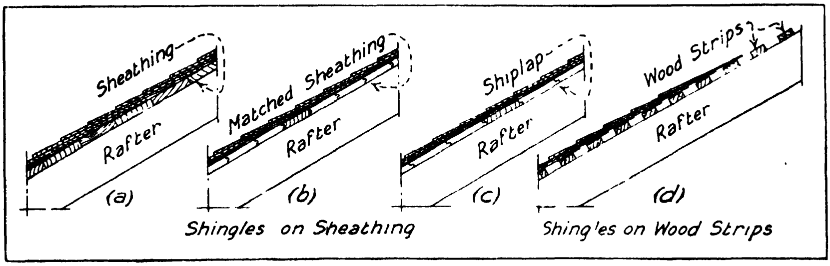


FIG. 210. Types of Sheathing for Wood Shingles

Shingle roofs should not be used with a flatter slope than 6 in. vertical to 12 in. horizontal. The chief use of wood shingles is in residence construction. The following discussion of wood-shingle roofs is taken from the Report of the Building Code Committee of the Department of Commerce:[1]

Probably no type of roof covering has caused more comment and discussion than the wooden shingle. The great danger of the wooden-shingle roof is from chimney sparks and flying brands from burning buildings or bonfires. The danger from chimney sparks is largely confined to wood or soft coal fires and the sparks resulting from the burning of chimney soot.

The wooden shingle has various well recognized merits. It is light in weight, has excellent insulating value, thus promoting comfort by equalizing temperatures, can be easily applied, furnishes attractive architectural effects, and high grade shingles properly laid produce a roof of excellent durability.

The main objection to the use of wood-shingle roofs is the fire hazard. Sparks or flying embers are more likely to roll or blow off from the smooth surface of a newly shingled roof than from an old roof with weather-worn shingles having curled and broken edges. For this reason any treatment of shingles, such as staining or creosoting, which will tend to maintain a smooth surface incidentally improves their fire resistance. Few if any of the compounds used for treating shingles directly increase their fire resistance.

When wooden shingles are used the very best grades of shingles available should be obtained, as they are more economical to the house owner in the long run than the cheaper grades and prolong the life of a smooth surface roof, thus promoting safety. For best results use edge-grain shingles free from knots and other imperfections and having a thickness at the butt not less than that represented by five shingles in 2 in. (four-tenths inch each). Shingles are

made in 16, 18, and 24 in. lengths. Sixteen-inch shingles on a roof having one-half pitch (6 in. in 12 in.) or greater should be laid 4½ in. to the weather; 18- or 24-in. shingles can be laid safely with larger exposure.

Ordinary wire nails are entirely unsuited to hold shingles. They rust out long before the shingles decay. Hot-dipped, zinc-coated, cut iron nails are best. Plain cut or galvanized wire nails will serve fairly well. The heads of nails should not be driven into the shingles. Untreated shingles should be thoroughly wet before laying.

Asphalt Shingles. Asphalt shingles are made of heavy asbestos felt and rag felt saturated or coated with asphalt, and with crushed slate or other material embedded in an asphalt coating to form the exposed surface. The most common shape is rectangular, 8 in. wide and 12½ in. long. As a rule, the shingles are of uniform thickness but some brands are tapered like wooden shingles. They are furnished as separate shingles or in strips 4 shingles wide. Various colors and patterns are available.

Asphalt shingles are nailed to tight wood sheathing, with each row lapping over the row below leaving from 4 to 6 in. exposed to the weather. They should not be used on slopes less than 6 in. vertical to 12 in. horizontal. They are relatively inexpensive and do not require painting.

Asbestos Shingles. Asbestos shingles are made of asbestos fiber and portland cement under pressure. They are made in various colors and sizes with thicknesses varying from ⅛ to ¼ in. and do not require painting. They are laid preferably in the same manner as wood and asphalt shingles using zinc- or copper-coated nails, and should not be used on slopes less than 6 in. vertical to 12 in. horizontal. A roofers' felt should be used over the sheathing.

Asbestos shingles are much stiffer, more durable, more attractive, and more fireproof than asphalt shingles. They are much more expensive than wood or asphalt shingles and somewhat cheaper than clay tile.

Metal Shingles. Metal shingles are made of sheet steel, galvanized or with a coating of tin, called *tin-plate*, or of tin and lead called *terne-plate*. They are also made of zinc or copper. Various patterns are available all of which are interlocking and are nailed to wood sheathing, covered with building paper, with nearly their entire surface exposed to the weather. Galvanized, tin-plate, and terne-plate shingles require painting but those of zinc and copper do not. Metal shingles are incombustible and will prevent fires caused by sparks and embers falling on the roof, but due to their high conductivity they do not afford as much protection to a frame roof structure, during severe exposure

to fire, as some other roof coverings with lower conductivity. Terne-plate shingles are quite commonly used but tin-plate shingles are rarely, if ever, used on account of their high cost.

A layer of roofers' felt $\frac{1}{16}$ in. thick placed between the shingles and the sheathing is quite effective in preventing quick ignition of the sheathing when the roof is exposed to burning brands or radiated heat. Asphalt-saturated felt papers should not be used under tin or terne shingles on account of destructive action of the asphalt on the tin.

Copper and not zinc-coated nails should be used with copper shingles and zinc-coated nails should be used with zinc shingles on account of the electrolytic action which may occur between zinc and other metals. This same precaution should be taken in selecting valleys, gutters, and other metal parts of a roof. In all cases where zinc is used in connection with another metal in exposed positions, care must be taken to prevent actual contact between the two metals because of the danger of electrolytic action, with resulting corrosion of the zinc. Satisfactory insulation can be secured by the use of portland cement, roofing cement, or asphaltum paint.

Because of their relatively low cost, their light weight, and their fair resistance to fire, metal shingles are sometimes used instead of some of the more expensive roof coverings.

ARTICLE 67. ROOFING TILE

Clay Tile. Clay tile are made by shaping moist clay in molds and burning. Many different patterns are available, the most common being French or Ludowici, Spanish, English, and mission or pan tile, as shown in Fig. 211*a* to *d*. Shingle tile are rectangular slabs about $\frac{1}{2}$ in. thick available in various widths up to 9 in. and lengths up to 14 in. Tiles of constant width are always used. They are laid in rows to break joints with the length exposed not more than one-half the length of the tile, minus 1 in. The rows may be regular or irregular.

All forms of tile are nailed to wood sheathing, wood nailing strips, gypsum, or nailing concrete. The nails should be preferably of copper but dipped galvanized steel nails are commonly used. Some forms of tile may be wired to closely spaced steel-angle sub-purlins but this practice is not common.

Special tile are available for the ridges and hips of roofs. The valleys should be made with sheet copper but in some localities galvanized steel gives satisfactory service. One or two layers of roofers' felt should be placed under the tile to serve as a cushion, to keep air currents from lifting the tile from beneath, and to shed water while injuries or defects are being remedied.

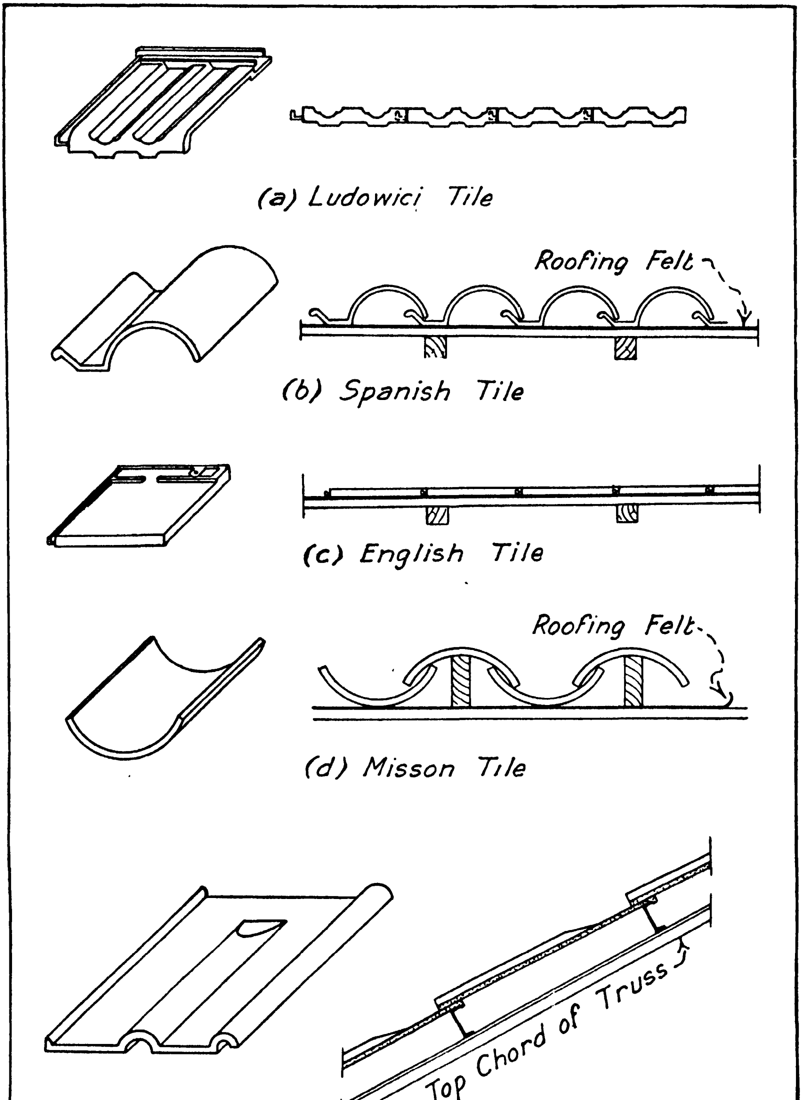


FIG. 211. Clay and Cement Roofing Tile

The usual forms of clay roofing tile should not be used on slopes less than 6 in. vertical to 12 in. horizontal. A special form of tile called promenade tile is placed on a waterproof base to form the floor of roof gardens. They are rectangular and vary in size from 6 in. to 12 in. with a thickness of 1 in. The waterproof base is constructed in the same manner as a tar-and-gravel roof but the gravel is omitted and the tile are bedded on a layer of hot tar or roofing pitch.

Clay tiles are fireproof, durable, and attractive but they are expensive and on account of their weight require a strong supporting roof.

Cement Tile. Cement tile similar to some forms of clay tile are on the market. They are made of portland cement and sand under pressure and are naturally cement colored, but they may be made of other colors by introducing the proper coloring material. The method of laying is the same as that described for clay tile.

Large red reinforced-cement tile covering an area 2 ft. wide by 4 ft. long, as shown in Fig. 211*e*, are on the market. These tile are laid directly on channel purlins properly spaced and are not fastened in any way. A projection at the upper end hooks over the purlin and keeps the tile from sliding down the slope. Special shapes are made for ridges, hips, and valleys. Large tile with wire-glass insets are available for use with the plain tile to serve as skylights.

Cement tile are fireproof and durable. They are cheaper but less attractive than clay tile. The large tile are suitable for industrial buildings but on account of the absence of any form of sheathing they rapidly conduct heat and may permit condensation on the under surface.

Metal Tile. Metal tile are made of sheet copper, zinc, or steel pressed into shape to imitate clay tile. Steel tile may be obtained with terne plate or galvanized and are always painted. Metal tile are nailed to wood sheathing covered with building paper or to nailing strips.

Copper or copper-coated nails should be used with copper tile, zinc-coated nails with zinc and steel nails with steel tile.

These tile are fireproof and are less expensive and lighter in weight than the clay tile which they imitate but they are not as attractive in color or in texture.

Terne plate and galvanized-steel tile require painting and it may be necessary to paint the copper and zinc tile to secure the desired effect but this is not necessary for protection.

In all cases where zinc is used in connection with another metal in exposed positions care must be taken to prevent actual contact between the two metals because of the danger of electrolytic action with the resultant corrosion of the zinc. Satisfactory insulation can be secured by the use of portland cement, roofing cement, or asphaltum paint.

ARTICLE 68. SLATE ROOFING

Slate roofing is made from the natural rock by splitting and shaping into rectangular pieces of the desired dimensions. Slate for roofing should be hard and tough and should have a bright metallic luster when freshly split. It should ring clear when supported horizontally on three fingers and snapped with the thumb of the other hand.

Slate is available in a great variety of colors such as gray, green, dark blue, purple, and red. It is furnished in about any size from 6 to 14 in. in width, 12 to 24 in. in length and $\frac{1}{8}$ to 2 in. in thickness, the common sizes being 12 by 16 in. and 14 by 20 in., $\frac{3}{16}$ and $\frac{1}{4}$ in. thick.

Roofs may be made of pieces of uniform size, thickness, and color but random sizes, thicknesses, and colors are also used.

Slate may be laid like shingles, each course lapping 3 in. over the second course below or they may be laid at random, care being taken to give sufficient lap. They are nailed to wood sheathing or nailing strips, or gypsum blocks, holes being punched in the slate at the factory. A layer of roofers' felt is used between the slate and the sheathing. The nails should preferably be copper, or yellow-metal slater's nails although redipped galvanized nails and copper-coated nails are commonly used.

Slates may be supported directly on steel sub-purlins to which they are wired. Slate roofs should not be used on slopes less than 6 in. vertical to 12 in. horizontal.

Slate flagging may be used on flat roofs for roof gardens by omitting the gravel on the ordinary tar-and-gravel roof and by bedding the slate in hot asphalt or roofing pitch.

Slate roofs are fireproof, durable, and attractive. All the slate used in this country comes from quarries in Vermont, Pennsylvania, and other eastern states; so the cost increases according to the distance from these sources of supply. Slate roofs may be classed as expensive.

ARTICLE 69. SHEET-METAL ROOFING

Method of Laying. Sheet-metal roofing of tin plate, copper, zinc, and lead is quite widely used. One of the most important factors to consider in the installation of sheet-metal roofs is the large amount of expansion which takes place and must be provided for or leakage will result. This is the chief factor controlling the design of the seams and the methods used in fastening the sheet metal to the roof. It may be laid with a *flat seam,* as shown in Fig. 212*a,* when the pitch of the roof is small or with a *standing seam,* as shown in Fig. 212*b,* on steeper pitches and running with the pitch of the roof. The seams are clinched tight, the

separation shown in the figures being for the sake of clearness. Cross seams are always flat. Flat seams are soldered but standing seams are not. The sheet metal is fastened by means of metal cleats 8 in. to 12 in. apart which are locked into the seams, the cleats being nailed to the sheathing.

The nails should be of the same material as the roofing where such nails are available in order to avoid galvanic action which may occur between dissimilar metals. Tinned nails should be used with tin and terne roofs, copper nails with copper roofs, and galvanized nails with galvanized-steel and zinc roofs. Nails should not be driven through

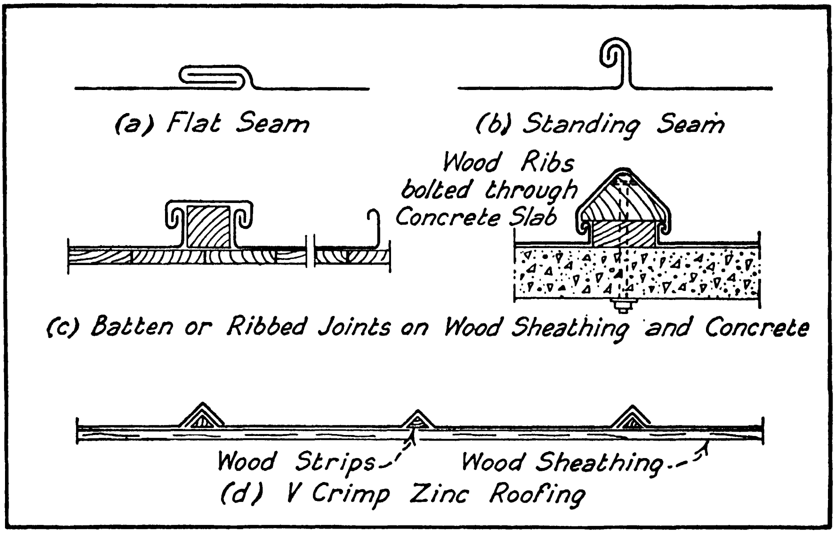


FIG. 212. Sheet-Metal Roofing

the sheets. Batten or ribbed roofs are formed by using wood battens or ribs running with the pitch of the roof. Sheet-metal troughs are fitted between these battens and caps are placed over the battens, as shown in Fig. 212*c*.

Sheet metal is placed over matched wood sheathing, a layer of roofing felt being used between the metal and the sheathing. An important function of this felt is to prevent quick ignition of the wooden decking when the roof is exposed to burning brands or radiated heat. It should be at least $\frac{1}{16}$ in. thick. Tar paper should not be used under tin roofs on account of the deleterious effect of the asphalt on the tin, but a rosin-sized paper is satisfactory.

In all cases where zinc is used in connection with another metal in exposed positions, care must be taken to prevent actual contact between the metals because of the danger of electrolytic action, with the resulting corrosion of the zinc. Satisfactory insulation can be secured by the use of portland cement, roofing cement, or asphaltum paint.

Tin and Terne Plate. Tin plates are made by dipping plates of sheet steel or iron in a molten bath of tin forming *bright tin plates,* or a molten bath of tin and lead forming *terne plates.* When leaving the molten bath the plates are usually passed through rolls, the pressure on the rolls determining the thickness of the plate. Bright tin plates are superior to terne plates but are so expensive that terne plates are usually used for roofing. The common sizes of sheets are 14 in. by 20 in. and 28 in. by 20 in.

Tin and terne roofs will last for many years if good material is used and if kept properly painted with red or white lead, iron oxide, metallic brown, or Venetian red, with pure linseed oil. Graphite or tar paints should not be used. Tin roofing is light and incombustible.

The methods used in laying tin plate are given at the beginning of this article.

Copper. Sheets of soft copper make a satisfactory roof covering which has a high initial cost but is durable and requires no painting. Exposure to the weather causes green copper carbonate to form on the surface which protects the remainder of the metal.

Zinc. Zinc sheets may be used to form a durable and satisfactory roof covering. Flat sheets may be used with flat or standing seams. Crimped sheets with longitudinal V-shaped crimps, spaced 12 in. apart, are available. These sheets cover a width of 24 in. and laps are made at the crimps provided at the edges. V-shaped wood strips are placed 12 in. apart on wood sheathing or nailing strips and the crimps are placed over these strips as shown in Fig. 212*d*.

Exposure causes dull gray zinc carbonate to form on the surface which protects the remainder of the metal. Zinc does not require painting. It should not come in contact with other metals or it will be attacked by electrolysis when moisture is present. Zinc is more expensive than terne plate but cheaper than copper.

Lead. Lead sheets are used for roofing to a limited extent. Lead is particularly suitable for curved or irregular surfaces for it can be easily stretched and worked to fit such surfaces without cutting. It has a large coefficient of expansion and is difficult to hold in place, particularly on pitched roofs.

A roofing known as *hard lead* is composed chiefly of lead but other materials have been added to increase the elastic limit and de-

crease the coefficient of expansion. This material has the advantages of ordinary sheet lead without the disadvantages. It may be used on any slope.

Galvanized Steel. Galvanized steel is made by dipping clean steel sheets in a bath of molten zinc. The zinc protects the steel from corrosion in proportion to the thickness of the zinc coating. Galvanized-steel sheets are available in rolls for use with standing seams, and, as shown for sheet zinc in Fig. 212, as V-crimp roofing. It is the cheapest sheet-metal roofing and has the shortest life.

ARTICLE 70. CORRUGATED STEEL, ASBESTOS-PROTECTED METAL, ZINC, ASBESTOS BOARD, AND GLASS

Corrugated Steel. Corrugated steel is widely used for roofing on industrial buildings. The type commonly used has corrugations $2\frac{1}{2}$ in. wide and $\frac{5}{8}$ in. deep, as shown in Fig. 213*a*, but other-sized corrugations shown in the figure are available. Corrugated sheets are 26 in. wide and may be obtained in lengths up to 10 ft. either painted or galvanized. The thicknesses in common use vary from 24 gage, which is $\frac{1}{40}$ in. thick, to 16 gage, which is $\frac{1}{16}$ in. thick, the gage to be used in any case depending upon the spacing of the supports, the load to be carried and the quality of the building.

Corrugated steel may be nailed to wood sheathing or may be supported directly by wood or steel purlins spaced 3 to 5 ft. apart. The sheets are lapped $1\frac{1}{2}$ or 2 corrugations on the sides and 6 in. or 8 in. on the ends depending on the slope of the roof. On slopes as flat as 2 in. vertical to 12 in. horizontal standing seams similar to those described for flat sheet metal should be used instead of side laps.

Where steel purlins are used they may be provided with nailing strips to which the corrugated steel is fastened as shown in Fig. 213*b* or the sheets may be held in place by straps passing around the purlins and riveted to the corrugated steel on each side of the purlin, as shown in Fig. 213*c*. Long malleable nails called *clinch nails* may be driven through the corrugated steel and clinched around the purlins, as shown in Fig. 213*d*. The side laps are held together by copper or galvanized-iron rivets spaced about a foot apart. All rivets and nails should be driven in the top of the corrugations to prevent leakage.

Since steel is a very good conductor of heat, it may be necessary to provide some form of lining for buildings where wood sheathing is not used and which are to be heated, or in which the condensation of moisture on the under side of them is to be prevented. This anti-condensation lining usually consists of a layer of wire netting placed directly on

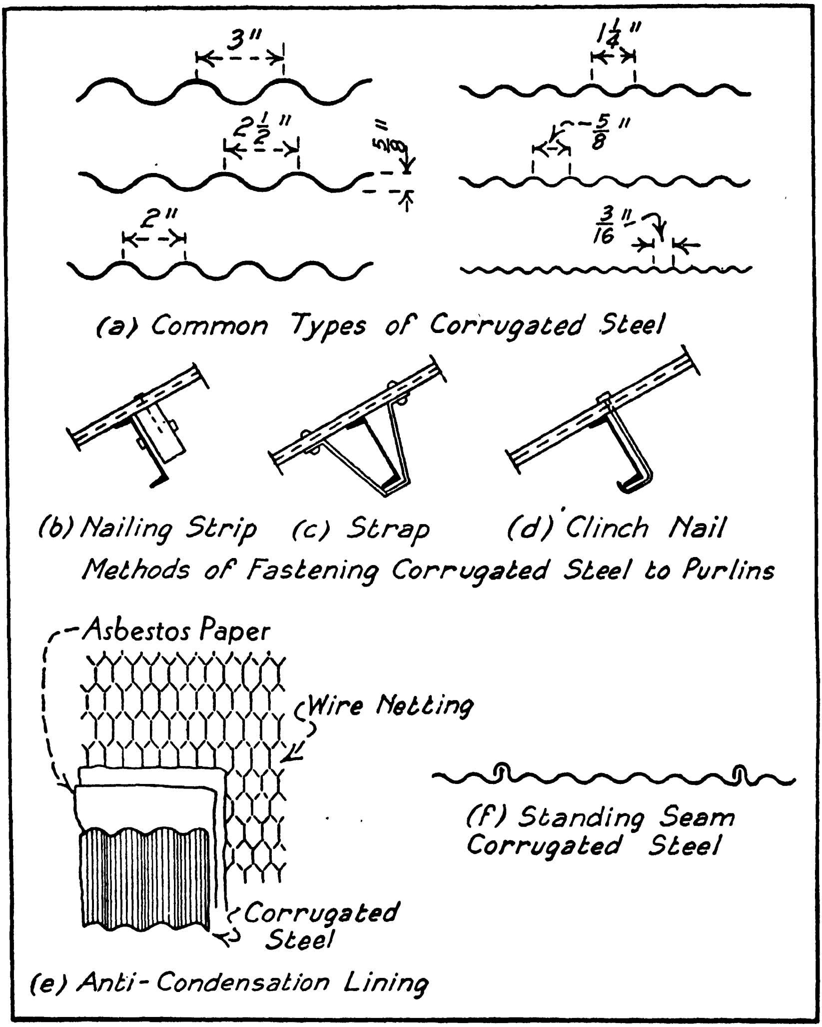


Fig. 213. Corrugated-Steel Roofing Details

the purlins and one or two layers of asbestos paper placed on the wire netting. The corrugated steel is placed over the lining as shown in Fig. 213*e*. The wire netting holds the asbestos paper in place and protects it.

When painted sheets are used they must be protected from corrosion by frequent painting.

Standing-seam corrugated steel roofing is shown in Fig. 213*f*. This roofing is available in thicknesses from 16 to 28 gage, painted or galvanized. Cleats are used to fasten the sheets to wood or steel purlins. No rivets or nails are used and the sheets are not punctured in any way in placing. The use of this type of roofing is the same as ordinary corrugated steel.

Asbestos-Protected Metal. Asbestos-protected metal consists of sheet steel covered first with a layer of asphalt, then a layer of asbestos, and finally a heavy waterproof coating. It may be obtained in flat sheets or corrugated sheets of the same size and shape as the plain corrugated sheets just described. The method of application is the same as for plain corrugated steel sheets but it does not require painting for it is well protected from corrosion and it is a poor conductor of heat and therefore may be used in places where the plain sheets are not suitable.

Because of their relatively light weight and fair insulating properties, corrugated sheets are extensively used on long-span roofs such as those of hangars and field houses. They are fastened directly to the purlins.

Corrugated Zinc. Corrugated zinc sheets may be obtained with corrugations $1\frac{1}{4}$ in. or $2\frac{1}{2}$ in. wide. The width of sheets is usually about 2 ft. and lengths up to 10 ft. may be obtained. On sheets with corrugations $2\frac{1}{2}$ in. wide, the corrugations are usually $\frac{5}{8}$ in. deep, but special sheets with corrugations $\frac{7}{8}$ in. deep are available.

Corrugated-zinc sheets are of various thicknesses from $\frac{1}{50}$ to $\frac{1}{25}$ in. They are used in the same manner as that described for corrugated steel sheets. In fastening to wood sheathing or nailing strips, zinc-coated cut or wire nails should be used; and, in fastening to steel purlins, zinc straps with tinned rivets and burrs, clinch nails with lead washers, or aluminum wire may be used.

Purlins may be spaced 5 ft. apart using sheets $\frac{1}{25}$ in. thick and with corrugations $2\frac{1}{2}$ in. wide and $\frac{5}{8}$ in. deep. The spacing may be increased to $6\frac{1}{2}$ ft., using sheets $\frac{1}{25}$ in. thick with $\frac{7}{8}$-in. corrugations.

Anti-condensation lining may be desirable with corrugated zinc and is applied in the same manner as that described for corrugated steel. Corrugated-zinc roofing is much more durable than corrugated steel, either plain or galvanized. The galvanized sheets depend upon the thin coating of zinc for protection from corrosion; naturally, the solid sheets of zinc are much more durable than the galvanized sheets. Zinc is not affected by sulphur fumes or smoke and does not require painting. Corrugated zinc is somewhat more expensive than galvanized steel.

Corrugated Asbestos Board. Corrugated sheets made of asbestos fiber and portland cement are used in the same manner as corrugated

steel. This material is a good non-conductor of heat and no trouble is experienced with condensation. It is durable and does not require painting.

Corrugated Wire Glass. Corrugated wire glass sheets similar in shape to corrugated steel sheets are available for use alone or in connection with corrugated steel or zinc to assist in lighting the interior of buildings. These sheets are ¼ in. in thickness and have wire netting embedded in the glass to strengthen it and to hold it in place when a break occurs. The glass sheets are not laid with side laps but the joint is covered with metal caps held in place by bolts passing between the sheets. The sheets are held to steel purlins by clips bolted to the metal cap covering the joint between sheets. Strips of asphaltic felt are placed over the purlins to act as a cushion for the glass.

ARTICLE 71. BUILT-UP AND PREPARED ROOFINGS

Built-Up Roofing. Built-up roofings consist of several layers of saturated felt cemented together with roofing cement. There are three types of saturated felts: asphalt asbestos felt, asphalt rag felt, and tar rag felt. The roofing cements used are asphalt or tar pitch. Asphalt cement is used with the asphalt-saturated felts and tar pitch with the tar-saturated felts.

Asphalts may be defined as solid or semisolid native bitumens obtained by refining petroleum, or solid or semisolid bitumens, which are combinations of the bitumens mentioned with petroleums or derivatives thereof, which melt upon the application of heat, and which consist of a mixture of hydrocarbons and their derivatives of complex structure.[2]

Tars may be defined as bitumens which yield pitches upon fractional distillation and which are produced as distillates by the destructive distillation of bitumens, pyrobitumens, or organic materials. *Coal tar* is produced by the destructive distillation of coal. *Gas-house coal tar* is produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal. *Coke-oven tar* is coal tar produced in by-product coke ovens in the manufacture of coke from bituminous coal. *Water-gas tar* is produced by cracking oil vapors at high temperatures in the manufacture of carburetted water-gas.[2]

A built-up roof applied to a concrete deck is illustrated in Fig. 214, each layer or *ply* lapping over the layer below and being cemented to it with roofing cement so that in no case will felt touch felt. The thickness of the roof is designated by the number of layers of felt at any point. A four-ply roof is four layers thick, as shown in the figure.

The top surface of built-up roofing may be given a heavy coat of hot roofing cement. This may be left without further treatment but it

usually has gravel or slag from $\frac{1}{4}$ in. to $\frac{5}{8}$ in. in size embedded in this coating to form a wearing surface. Tile, slate, and concrete wearing surfaces are commonly put over built-up roofs to form floors for roof gardens, etc.

Built-up roofs are usually used only on roofs with a very slight pitch such as $\frac{1}{2}$ in. to the foot because the cementing material will flow in hot weather but by using special materials they may be applied to sloping roofs. The slag or gravel wearing surface is not used on sloping roofs.

A special form of built-up roof designed for very long life such as required on monumental structures consists of two or three plies of sheet lead laid in asphalt over a layer of felt cemented to concrete or gypsum

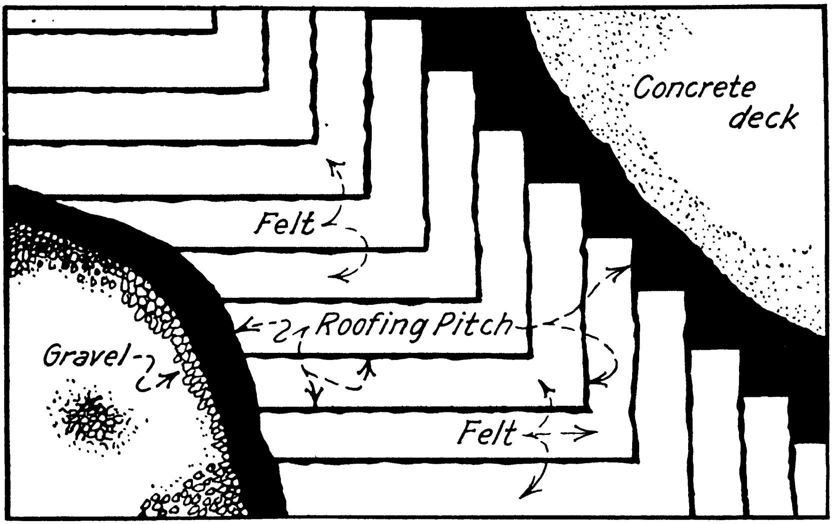


FIG. 214. Four-Ply Built-Up Roofing on Concrete Deck

decks with asphalt. If a wood deck is used the felt is nailed to the deck. After the lead has been placed, the entire surface is rolled with a roller and is then coated with hot asphalt. The lead sheet acts as a seal which prevents the evaporation of the volatile oils in the under layers of bituminous material and thereby increases the life of the roofing.

Prepared Roofing. Prepared roofings consist of asbestos felt or rag felt saturated with asphalt and assembled with asphalt cement at the factory to form strips about 1 yd. wide and 12 yd. long. These roofings are equivalent to two-ply or three-ply built-up roofings. They may have a plain surface or may be surfaced with crushed slate, sand, mica, or other mineral surfacing. Roofing of this type is furnished in rolls and is sometimes called *roll roofing*. It is ready for use and is some-

times called *ready roofing*. It is also known as *composition roofing*. Several grades differing in weight, durability, and fire resistance are available.

Prepared roofing is nailed to wood sheathing using special nails with large heads, the edges of the roofing being lapped about 2 in. and cemented. The nails are placed in the laps. This type of roofing is cemented to concrete with roofing cement.

Prepared roofings may be used on any slope greater than 2 in. vertical to 12 in. horizontal. On the flatter slopes great care must be used to have the joints cemented tightly. They are inexpensive but have a relatively short life.

One form of prepared roofing has a cloth surface for use on roofs which are subjected to foot traffic.

Canvas Decking. Deck cloth is a canvas treated by a process which makes it waterproof and increases its wearing qualities. It is stretched tight, held in place with closely spaced tacks, and painted with white lead and oil colored as desired.

Untreated canvas may be used for roof decking by bedding it in a coat of wet paint, lapping at least 1½ in., and placing tacks at the edges and on the laps ½ or ¾ in. apart.

These types of roofing are used on decks subjected to foot traffic. They are relatively inexpensive but do not give the attractive and durable roof obtained with promenade tile.

ARTICLE 72. COMPARISON AND USES OF ROOFING MATERIALS

General. The factors which must be considered in selecting a roof covering are:

1. Slope of roof.
2. Durability.
3. Initial cost.
4. Maintenance cost.
5. Resistance to fire.
6. Weight.
7. Type of roof construction.
8. Appearance.

The relative importance of these factors will vary with different classes of buildings. These factors have been considered to a certain extent in the previous articles but this article will serve as a summary.

Slope of Roof. All forms of shingles, tile, and slate require a slope of at least 6 in. vertical to 12 in. horizontal. Some forms of clay tile and slate flagging may be used to replace the gravel on flat tar-and-gravel roofs subjected to foot traffic. Corrugated sheets should not be used on a slope of less than 4 in. vertical to 12 in. horizontal. Sheet-metal roofs may be used on practically any slope, flat or steep. Prepared roofing may be used on any slope sufficient to provide drainage, if the joints are

properly cemented. Built-up roofs may be used on any slope if the materials are properly selected, but their most extensive use is on flat roofs.

Durability. The length of life of any roofing material depends upon so many factors which are variable that it is useless to attempt to give any more than comparative figures. The following classification will give an idea of the relative durability but should be considered only as a general indication of the durability:

1. *Long-lived:* clay tile, slate, copper, zinc, and lead.
2. *Medium-lived:* tin, asbestos-protected metal, asbestos shingles, cement tile, built-up roofing, wood shingles.
3. *Short-lived:* asphalt shingles, corrugated steel, prepared roofing.

Various destructive agencies must be considered in connection with durability. Clay tile and slate may break if walked upon, even if only while repairs are being made; slate and prepared roofings may suffer severely in hail storms — sheet steel, in any form, is particularly vulnerable to corrosive gases and salt air. Wind may have serious effects on roofs of tile, asphalt shingles, and prepared roofing. Tin and all forms of sheet steel must be kept painted. If roofs are to be subjected to foot traffic a canvas decking may be used, or promenade tile or slate on a waterproof base.

Initial Cost. The initial cost of roofing materials varies from time to time and varies also with the locality. For instance, slate roofing comes from Vermont, Pennsylvania and other eastern states and is therefore more expensive in the West than in the East on account of freight charges. Wood shingles are cheaper on the Pacific coast than in most other localities. Clay tile are manufactured at many points throughout the country. The following classification will give an idea of the relative cost of roofing materials:

1. *Expensive:* clay tile, slate, sheet copper, lead.
2. *Medium-priced:* zinc, tin, asbestos-protected metal, asbestos shingles, cement tile, metal shingles, metal tile.
3. *Low-priced:* asphalt shingles, wood shingles, corrugated steel, built-up roofings.
4. *Cheap:* prepared roofings.

Cheap prepared roofings may cost as little as 5 cents per square foot whereas the more expensive forms of tile roofs may cost as much as 60 cents per square foot.

In determining the cost of a roof covering, the indirect cost due to the effect of the weight on the cost of the supporting structure must be considered. In this respect various forms of shingles, sheet metal, and

prepared roofings have advantage over tile and slate. The cost of preparation of the supporting structure to receive the roofing is also a factor to be considered.

Cost of Maintenance. On certain classes of roofing materials, there is a continual charge for maintenance in the form of painting; on others, only the damage due to accident or unusual hail or wind storms need be considered; whereas on others there is practically no expenditure for maintenance. The following classification will give an idea of the relative cost of maintenance of various roofing materials:

1. *Frequent painting or repairs:* wood shingles; corrugated steel; tin and galvanized iron sheets, tile, and shingles; prepared roofings.
2. *Occasional repairs:* clay tile, slate, cement tile, asphalt shingles, asbestos shingles.
3. *Very little maintenance:* built-up roofing, copper, zinc and lead.

Resistance to Fire. A very important factor in the selection of a roofing material is the resistance to fire. Many building codes will not permit wood shingles to be used except in isolated locations. The actual resistance of the roof covering to fire is of more importance when the supporting structure is timber than when it is of fireproof construction. Sheet-metal roofing on roofers' felt will protect wood sheathing from being ignited from sparks and will protect sufficiently against a moderate exposure to fire. Clay and cement tile and slate are more effective than the materials just mentioned, although slate will decompose at high temperatures. Built-up roofing, asbestos shingles, and asphalt-impregnated asbestos roof coverings will withstand quite severe fire exposures. (See the discussion on fire resistance under the heading Wood Shingles in Art. 66.)

Weight. The effect of weight on the cost of the supporting structure has been mentioned. If one roofing material is to be replaced with another, the weight may often be a determining factor in the choice of material on account of the strength of the roof construction already in place. The weight of a given roofing material depends upon its design, its thickness, and other factors, but the following weights in pounds per square of 100 sq. ft. (page 533) will give an idea of the relative values.

Type of Construction. The methods used in fastening the various roofing materials to the supporting roof construction make it necessary to consider the nature of this construction in selecting a roof covering; however, the type of construction of the supporting roof will usually have been adapted to the roof covering which has been selected.

Wood sheathing, gypsum, or nailing concrete may all be used to receive the nails which hold shingles, slate, tile, or sheet metal in place,

WEIGHTS OF ROOFING MATERIALS

(In Pounds per Square)

Heavy	Medium	Light
Clay tile.......1000–2000	Wood shingles ..200–300	Copper..........80–130
Slate.......... 500–1000	Asphalt shingles 150–300	Terne plate.......60– 75
Built-up roofing 300– 600	Galvanized steel 125–200	Prepared roofing. .35– 80
Asbestos-cement shingles...... 400– 700		

and are suitable for prepared roofing and built-up roofing which are to be cemented down with hot roofing pitch or similar material. If a roof is to be exposed to severe winds, nails driven in gypsum or nailing concrete may work loose; therefore, it is desirable to use wires which pass through holes, drilled or punched in the gypsum or supporting tile, and which are fastened to the under side of these materials.

Concrete construction, in its various forms, is suitable for the application of coverings such as prepared roofing or built-up roofing which are to be cemented down with hot roofing pitch or similar material. Nailing concrete may be used for coverings which are to be held in place with nails. Nailing strips may be fastened to concrete to receive any form of roofing, but such strips are not usually necessary on wood or gypsum, nailing concrete and, where necessary, they are more easily fastened to these materials than to concrete.

Where roof coverings are to be supported directly on the members of the structural frame without sheathing or other material to form a continuous surface, it is necessary to use corrugated steel or zinc sheets, corrugated asbestos board, or large reinforced-cement tile. In some cases, closely spaced sub-purlins may be provided to support ordinary tile or slate which is wired in place.

Appearance. The kind of roof covering selected for a building will depend largely upon whether or not the roof may be seen. If the roof is flat, a built-up roofing will be very suitable. If the roof is exposed to view, the roofing will be selected to harmonize with the remainder of the building, attention being given to the factors which have been considered in the previous paragraphs. Wood shingles are attractive, and this type of roofing is extensively used on residences in spite of the fire risk and the cost of frequent painting. Asphalt shingles are replacing wood shingles on account of the supposedly smaller fire risk and the saving in painting, but they are not generally considered as attractive as wood shingles. Large cement tile are quite satisfactory in appearance for industrial buildings; and on such buildings where appearance

is not an important factor prepared roofing or corrugated sheets of various materials may be used.

Geographical Distribution. The predominant types of roofing materials, as indicated by a survey by the Bureau of Standards,[3] are shown in Fig. 215. In general, wood shingles are more commonly used than any other roofing material in the western states, and asphalt shingles in the eastern states; but slate predominates in the slate-producing areas in the Middle Atlantic states.

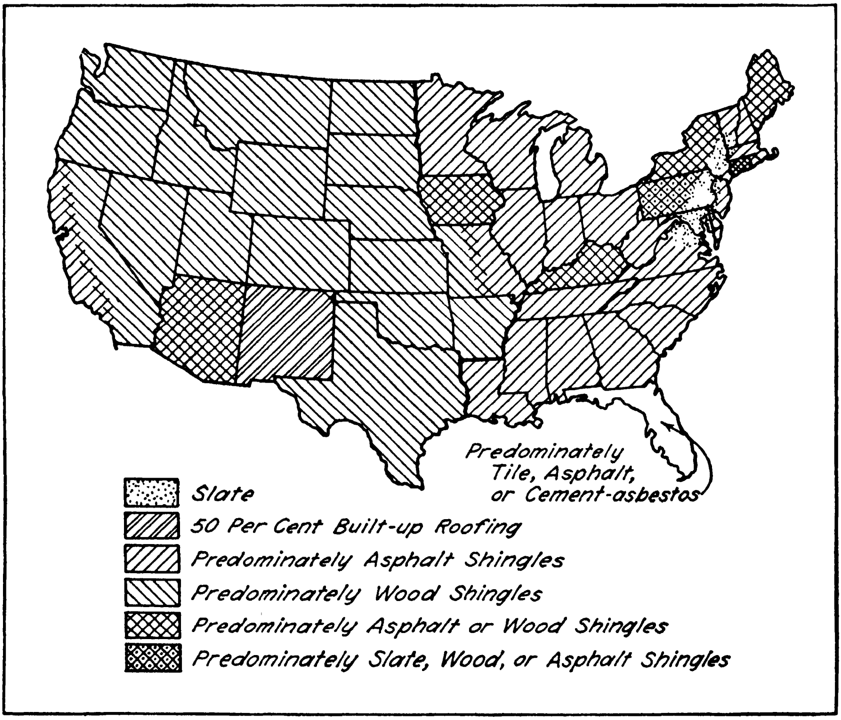


FIG. 215. Geographical Distribution of Predominant Roofing Materials

Roofing Accessories. The most expensive and most durable sheet metal used for roofing accessories is copper. A survey by the Bureau of Standards[3] indicates that copper is usually used with slate and tile roofs, and to a less extent with asbestos-cement shingles. Galvanized steel is rarely used with tile and slate, quite often with asbestos-cement shingles, and more than any other material with wood shingles. Roll roofing is usually used for valleys with asphalt shingles, but galvanized steel is quite common and terne plate is often used.

Galvanized steel is used far more than any other material for flashings, gutters, and downspouts, but this is doubtless due to the extensive use of the cheaper roofing materials. Copper is usually used with slate and tile roofs.

Summary. In high-class buildings and residences with sloping roofs exposed to view, clay tile, slate, asbestos shingles, and sheet copper may be considered the most suitable roofing materials.

On less expensive buildings with sloping roofs exposed to view, asphalt or wood shingles, small cement tile, zinc, or tin may be used. Metal tile may also be used on this class of structure, but they are often objected to because they are merely an imitation of real tile.

On the cheapest class of buildings with sloping roofs, corrugated zinc or steel or prepared roofing may be used.

On industrial buildings, the question of appearance is of less importance than durability. On sloping roofs large reinforced-concrete tiles are suitable or if a cheaper roof is desired, corrugated zinc or steel may be used with or without anti-condensation lining. Asbestos-protected metal is expensive but makes an excellent roof. Prepared roofing mopped on may be used.

For flat roofs, built-up roofing is certainly the most satisfactory but prepared roofing mopped or nailed on may be used to lower the initial cost.

Roofs which are required to withstand foot traffic may be covered with cloth-covered prepared roofing, canvas decking, or untreated canvas bedded in oil paint if a low-priced roofing is desired. If the use of a more expensive roof is warranted, clay tile or slate bedded on a waterproof base may be used. Asphalt mastic, as described in Art. 61, is also used.

REFERENCES

1. "Recommended Minimum Requirements for Small Dwelling Construction," Building Code Committee, Department of Commerce 1922, Revised 1932.

2. Standard Definitions of Terms Relating to Materials for Roads and Pavements, American Society for Testing Materials, 1939.

3. WALDRON, LEO J., and HUBERT R. SNOKE: "Roofing in the United States—Results of a Questionnaire," Report BMS57, National Bureau of Standards, 1940.

4. WALDRON, LEO J.: "Metallic Roofing for Low-Cost House Construction," Report BMS49, National Bureau of Standards, 1940.

5. SNOKE, HUBERT R., and LEO J. WALDRON: "Survey of Roofing Materials in Southeastern States," Report BMS6, National Bureau of Standards, 1938.

6. SNOKE, HUBERT R., and LEO J. WALDRON: "Survey of Roofing Materials in the Northeastern States," Report BMS29, National Bureau of Standards, 1939.

7. "Sweet's Catalog File," F. W. Dodge Corporation, issued annually.

8. SNOKE, HUBERT R.: "Asphalt-Prepared Roll Roofings and Shingles." Report BMS70, National Bureau of Standards, 1941.

CHAPTER XI

PLASTER AND STUCCO

ARTICLE 73. DEFINITIONS AND GENERAL DISCUSSION

Definitions and Uses. *Plaster* is a material used in a plastic state, which can be troweled, to form a hard covering for *interior* surfaces, walls, ceilings, etc., in any building or structure.[1]

Stucco is a material used in a plastic state, which can be troweled, to form a hard covering for *exterior* walls or other exterior surfaces of any building or structure.[1]

Mortar is a material used in a plastic state which can be troweled, and becomes hard in place, to bond units of masonry structures.[1]

The terms plaster, stucco, and mortar are used without regard to the composition of the material but refer only to the use and location of the material.

Materials. The mortar used in plastering interior surfaces is made of sand and water mixed with lime, gypsum plaster, Keene's cement, or portland cement, as a cementing material. On exterior surfaces, portland cement stucco and a special preparation called magnesite stucco are used. For detailed description of the materials used in plaster and stucco, see Art. 9.

Bases. Plaster and stucco are applied to bases of brick, stone, hollow tile, or concrete masonry, and to wood lath, metal lath, and gypsum lath, or similar materials furnished in sheets.

Placing. The mortar is applied with a special *trowel* and is brought to a true surface with a *darby* and a long straightedge called a *rod*. These tools are illustrated in Fig. 216*a*. Wood or metal *grounds* are placed around all openings and along the top of the wall base, as shown in Fig. 216*b* and *c*, to serve as guides in finishing the plaster. These guides may also serve as nailing strips for the wood finish. It is also necessary for a plasterer to build up guides of plaster to assist in securing a true surface. Such a guide is called a *screed*. It is a part of the brown coat. The surface may be finished with the steel trowel to give a smooth finish, it may be finished with a rough *float* to give a sand finish, or special finishes may be formed in various ways.

Coats. Three coats of plaster are usually applied on wood or metal lath. The first coat is called the *scratch coat* because its surface is scratched to give a better bond to the second coat, which is called the *brown coat* on account of its color. The brown coat is finished accurately to a true surface ready to receive the *finish coat.* The surface of the brown coat is formed by a straightedge or a rod which is worked

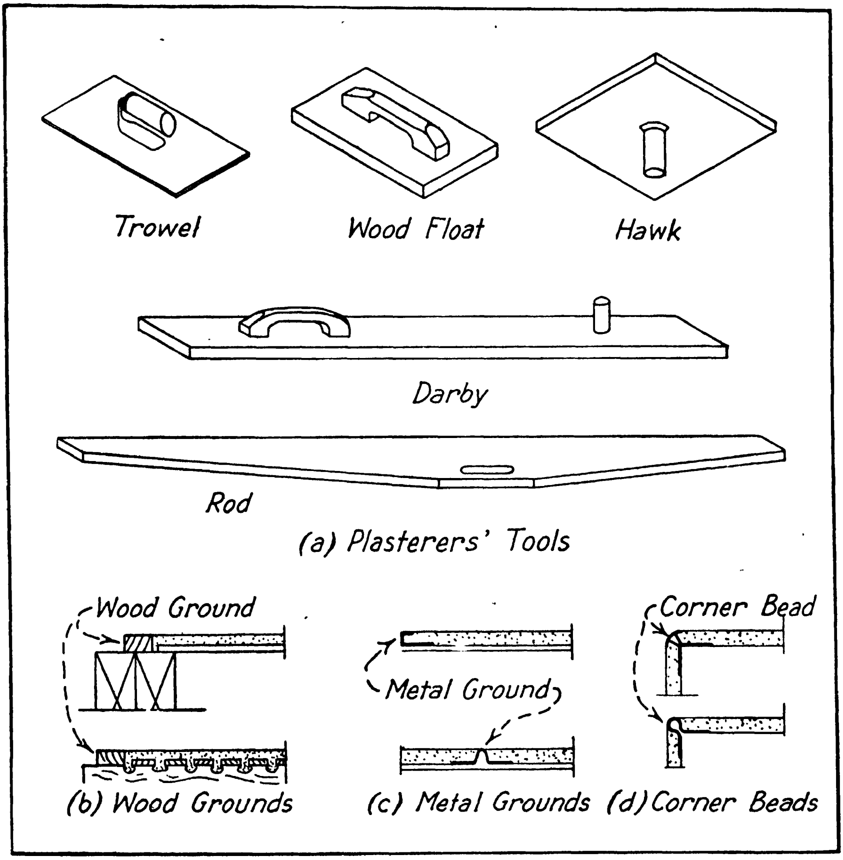


FIG. 216. Plasterers' Tools, Grounds, and Corner Beads

up and down with the lower end bearing against a ground along the bottom of the wall, and its upper end bearing against a screed built up of plaster. It is usually necessary to place a screed at the midheight of a wall with ordinary ceiling heights because it is not feasible to plaster the entire height in one operation, the upper part requiring a scaffold. Specifications sometimes require that the vertical distances between

horizontal screeds shall not exceed 5 ft. In cheap work screeds are usually omitted. The *finish coat* is often called the *white coat, skin coat,* or *putty coat* and will be described later. Usually each coat is permitted to dry out thoroughly before the next coat is applied, but in order to save scaffolding the brown coat is sometimes applied immediately after the scratch coat. This is called *drawn work* or *laid-off work* and is not as satisfactory as that obtained by the usual method.

In cheaper work on lath, the scratch and the brown coat may be combined into one coat, placed in one operation, and finished ready to receive the finish coat. This is called *two-coat work.*

On brick, stone, hollow tile, and other classes of masonry, the scratch coat is not required but is often used.

The total thickness of the plastering usually varies from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. though in some cases a thickness of $\frac{7}{8}$ in. is required. In filling out irregularities, and in making walls plumb a greater thickness is often necessary. A common requirement for the thickness of grounds is $\frac{3}{4}$ in. for $\frac{1}{4}$-in. gypsum lath, wood lath, and metal lath; $\frac{7}{8}$ in. for $\frac{3}{8}$-in. gypsum lath, and $\frac{5}{8}$ in. for brick and hollow-tile walls. The grounds are so placed that they include the thickness of the lath and plaster board, as shown in Fig. 216*b* and *c*. The vertical external corners of plaster are protected by *corner beads* as shown in Fig. 216*d*. These are often used as guides on other external corners.

Ornamental Plastering. Ornamental features may be applied in two ways. Such linear members as cornices, coves, and moldings are *run* in place, the outlines being cut into the wet plaster by sheet-metal templets. Designs which can not be run are *cast* in molds and then placed in position.

Accessories. Sheet-metal accessories are available for use with any type of plaster base. They include *corner beads,* which protect exposed corners and assist the plasterer in forming a true corner; *base beads* or *base screeds,* which are used to divide a plastered wall surface and a cement base and give the plasterer a straight edge to strike to; *picture molds,* which provide a slot to receive picture hooks but are otherwise concealed by the plaster; and *arch corner beads* which guide the plasterer in forming an arch and protect the corners.

ARTICLE 74. BASES FOR PLASTER AND STUCCO

The various plaster and stucco surfaces described in Art. 75 may be applied to many types of bases, as shown in the following classification:

1. Masonry
   a. Brick, stone, and concrete
   b. Hollow tile, and gypsum blocks
2. Wood lath
3. Metal lath
   a. Expanded metal
      (1) Diamond and rectangular mesh
      (2) Ribbed lath
   b. Integral lath
      (1) Expanded metal
      (2) Sheet metal (not expanded)
   c. Sheet lath
      (1) Flat perforated
   d. Wire lath
      (1) Plain
      (2) Stiffened
4. Gypsum and fiber lath and board

Masonry. Plaster may be applied directly to brick, stone, and concrete masonry. Two coats only are usually required, the brown coat and the finish coat, but it is often necessary to fill in irregularities in a stone wall before the brown coat is applied. Many architects specify a special bond plaster for concrete surfaces.

Except in very dry climates, plaster should not be applied directly to the inside surface of brick, stone, or concrete exterior walls because driving rains will soak through the walls, and stain the plaster or cause it to fall off. Condensation of the moisture in the atmosphere of the rooms on the cold inner surfaces of outside walls also causes trouble. For these reasons and to provide better insulation, an auxiliary surface to receive the plaster is constructed on the inside of the exterior walls. This is known as *wall furring* and provides an air space between the masonry wall and the plastered surface. For methods of furring, see Art. 24.

Interior partitions are very commonly constructed of hollow tile or of gypsum blocks, as described in Art. 27. The surfaces of these blocks are roughened or scored to form a better bond with the plaster. Portland cement plaster will not adhere to gypsum blocks. Hollow clay tile is used for exterior walls and on account of the air space in the tile may not require furring, but furring is desirable in this case also. Cavity walls, as described in Art. 25, do not require furring. Gypsum blocks are never used for exterior walls because they will not withstand the action of water.

Wood Lath. Wood lath are made of white pine, yellow pine, redwood, cypress, fir, and spruce. They are $\frac{1}{4}$ or $\frac{3}{8}$ in. by $1\frac{1}{2}$ in. in section

and are commonly 48 in. long but are also manufactured in 32-in. lengths. They are laid $\frac{3}{8}$ in. apart on ceilings and $\frac{1}{4}$ in. on side walls so that the plaster may be forced partly around the lath forming a key, as shown in Fig. 216*b*.

Wood lath are cheaper than metal lath but are not as satisfactory on account of their combustibility and because plaster applied over wood lath is more likely to crack than when applied over metal lath. Wood lath are usually fastened directly to wood studding spaced 12 in. or 16 in. but they are also used on exterior walls over wood sheathing. In this case 1-in. by 2-in. furring strips spaced 12 in. or 16 in. should be used to give a space behind the lath for the plaster to form a key.

Wood lath should be wet thoroughly so that they will swell before the plaster is applied. If this precaution is not taken the lath will absorb water from the plaster and swell, thus causing cracks in the plaster.

Metal Lath. Metal lath is furnished in a great variety of forms, as listed in the classification at the beginning of this article. All metal lath is furnished either painted or galvanized. It is fireproof, and plaster applied over metal lath is less likely to crack than if applied over wood lath. All metal lath, except wire lath, is made in sheets 8 ft. long by 24 and 27 in. wide. It is shipped in bundles containing several sheets. Metal lath is nailed to wood studding or furring strips and is wired to metal supports. Wire lath is furnished in rolls.

Expanded metal is formed by cutting sheet metal in such a way that it may be pulled out or expanded to cover a much larger area than that of the original sheet metal, as shown in Fig. 183. Expanded metal lath is used where the supports are close together. Diamond and rectangular mesh are satisfactory for a 16-in. spacing on side walls and on ceilings, whereas ribbed lath may be used for considerably greater spacings, the spacing depending upon the type of lath.

Integral lath is so designed that it does not require studding for support. It is used chiefly in solid partitions.

Sheet-metal lath is not expanded but is punched in such a manner that the plaster when applied can secure a firm grip on the lath.

Wire lath may be woven or welded; it has a mesh $\frac{3}{8}$ in. to $\frac{1}{2}$ in. square, and may be obtained with stiffeners or without stiffeners, as shown in Fig. 183, in rolls 36 in. wide and containing 150 lin. ft. These stiffeners are V-shaped metal or round rods and are spaced 8 in. apart. Lath without stiffeners may be used on studding spaced 12 in., and in some cases 16 in., but for greater spacings stiffeners are required. When the lath is applied over wood sheathing or other flat surfaces, the stiffeners act as furring strips to hold the lath away from the flat sur-

faces and enable the plaster to form a key. When the lath is used over wood sheathing for exterior surfaces, a waterproof paper is placed between the sheathing and the lath.

Gypsum lath consists of a gypsum plaster core and surfaces of heavy paper pressed together in sheets $\frac{3}{8}$ in. thick and 16 in. wide by 32 and 48 in. long. It is used as a substitute for wood and metal lath and is nailed to wood studding or furring strips spaced 12 in. or 16 in. It can be sawed to any desired size. Gypsum plaster adheres satisfactorily to the surface of gypsum lath, but lath perforated with holes about $\frac{7}{8}$ in. in diameter to improve the bond are available. Gypsum lath is fire-resistant and is cheaper than metal lath. Its use is confined to interior surfaces. Gypsum lath is also called rock lath.

Fiber lath is made of cane fiber or of other fibrous materials pressed into sheets 18 by 24 in. and $\frac{1}{2}$, $\frac{3}{4}$, and 1 in. thick. Lengths up to 12 ft. are available. In addition to serving as plaster bases, these materials have considerable resistance to the passage of heat. They are useful as heat insulators when placed on the ceiling of the top story of buildings and for rooms in the attics of residences. See Art. 76.

ARTICLE 75. PLASTER AND STUCCO SURFACES

Classification of Materials. The cementing materials commonly used for plaster surfaces are the gypsum plasters, lime, and portland cement, and those used for stucco surfaces are portland cement and magnesite stucco. Of these materials those most extensively used are the gypsum plasters for interior plastering and portland cement for stucco.

Gypsum Plasters

Classification. Gypsum plasters are available in a great variety of forms designed to meet the special requirements of the various uses to which such plasters are put. In preparing the following paragraphs the Standards of the American Society for Testing Materials have been extensively used.[1] The process of manufacture of gypsum plasters is given in Art. 9.

Gypsum neat plaster is a plastering material in which not less than 60.5 per cent of the cementitious material is calcined gypsum, $CaSO_4 \cdot \frac{1}{2}H_2O$, mixed at the mill with other materials to control the working quality, setting time, and the fibering. Gypsum neat plasters are furnished with hair fiber to serve as a binder for use, with sand, in scratch coats on wood and metal lath and gypsum lath, and without hair fiber for use in second or brown coats over scratch coats or for the first coat on masonry surfaces where a scratch coat is not required.

Gypsum ready-sanded plaster (prepared plaster) is a plastering material in which the predominating cementitious material is calcined gypsum, and which is mixed at the mill with all the constituent parts, including sand, in their proper proportions. It requires only the addition of water to make it ready for use. The ready-sanded plaster for the scratch or first coat should contain not more than two-thirds by weight of sand. The other third consists of gypsum neat plaster. The ready-sanded plaster for the brown or second coat consists of not more than 3 parts by weight of sand and the remaining 1 part of gypsum neat plaster.

Gypsum wood-fibered plaster is a gypsum plaster in which wood fiber is used as an aggregate with gypsum neat plaster as the cementing material. For best results this plaster is used without sand and produces a light, tough, durable, sound-absorbing coating, but it is commonly mixed with an equal amount by weight of sand. Wood-fibered plaster is often used for one-coat work.

Bond plaster is a plaster with high adhesive properties which is made especially for use as a first coat on interior concrete surfaces. It is a ready-mixed plaster which requires only the addition of water to be ready for use.

Several gypsum plasters are manufactured for use in finish coats. One of these is suitable for a white troweled finish, another for a gray troweled finish and another for a gray sand-float finish. These plasters contain no lime. *Gaging plaster* is prepared for use with lime putty to form a lime-putty finish, 1 part by volume of gaging plaster being mixed with 3 parts of lime putty immediately before use.

Gypsum molding plaster is a material consisting essentially of calcined gypsum for use in making interior embellishments, cornices, etc.

Keene's cement is anhydrous gypsum, the set of which is accelerated by the addition of other materials. It is harder, stronger, and more water-resistant than other gypsum plasters and is also more expensive.

Gypsum plasters are also called *hard-wall plasters, cement plasters,* and *patent plasters.*

The hair in the *hair-fibered plasters* is used to bind the material together until it has set. It is usually manila or jute fiber. Shredded wood fiber is used in *wood-fibered plaster.*

Mixing. In mixing gypsum plaster, a clean tight box about 3 ft. wide and 6 ft. long, raised about 4 in. at one end, is used. This box should be thoroughly cleaned after mixing each batch and the tools should be kept clean because the presence of plaster which has set tends to hasten the setting of a new batch. For this reason, the remains of an old batch should never be mixed with a new batch. Only the

quantity which can be applied in one hour should be mixed at one time and mortar which has started to set should not be *retempered* by adding more water and remixing. Tools should not be rinsed in the gaging water. The plaster and sand should be thoroughly mixed dry and placed in the high end of the box before adding water. The water should be added at the low end and the mixing should be done by pulling the plaster slowly into the water with a hoe, allowing it to soak a few minutes, and mixing thoroughly.

The sand should consist of fine granular material composed of hard, strong, durable, uncoated particles which are free from injurious amounts of saline, alkaline, organic, or other deleterious substances.[1] It should be graded from fine to coarse.

The water used for mixing should be fresh, pure and clean. The presence of excessive amounts of mineral or organic substances in the water may be harmful.

Proportions. The mixture used for the scratch coat on wood and metal lath is 1 part, by weight, of fibered plaster to 1½ or 2 parts of sand and that for the brown coat is 1 part, by weight, of plaster to 2 or 3 parts of sand. For application to brick and tile, 2½ or 3 parts by weight of sand to 1 part of unfibered plaster may be used. Wood-fibered plaster is used without sand if its full advantages are to be secured or it may be mixed with 1 part of sand. Bond plaster should be used without sand for the best results. The ready-sanded plasters are ready for use without further additions. Lime putty finishes are mixed in the proportions of 1 part by volume of gaging plaster to 3 parts of lime putty. Sand float finish is obtained by a mixture of 1 part by weight of unfibered plaster and 1 part of sand which passes a No. 12 screen. The prepared finishes usually require no additions except water.

Application. Wood lath should be thoroughly soaked several hours before plastering. If this is not done the lath will absorb water from the plaster and swell after the plaster is applied, thereby causing lath cracks in the plastered surfaces. Masonry surfaces should be wetted a sufficient amount to reduce the suction to such an extent that they will not absorb the water which is necessary for the proper setting of the plaster but they must not be too wet or the plaster will not adhere to them. Gypsum lath should not be wetted.

The tools used in plastering are shown in Fig. 216*a*. The scratch coat over metal lath should be applied with a trowel using sufficient pressure to form a good key and should form a thin coat over the lath. Too much pressure will cause a waste of material by causing it to drop off behind the lath. This coat is scratched or roughened before it has

set to form a better surface for the bonding of the brown coat. A scratch coat is not necessary on masonry walls but crooked and uneven walls should be straightened by filling in the low places with mortar before the brown coat is applied. The brown coat should be applied after the first coat has set hard but before it is dry. Considerable pressure should be used in applying this coat and the surface should be straightened with rod and darby leaving it roughened ready to receive the finish coat. The brown coat should be kept back from the face of the grounds to allow for the finish coat. After the brown coat has dried it is sprinkled lightly and then the finish coat is applied. If a *lime-putty finish* is to be used, it is applied in a coat about $\frac{1}{8}$ in. in thickness and troweled to a glazed finish with a steel trowel the surface being kept moist during the process by applying water continuously with a brush. The *sand-float finish* is secured by going over the finish coat consisting of gypsum plaster and sand with a wood or cork float producing a finish which resembles coarse sandpaper. The *troweled finish* using gypsum finish plaster is worked in the same way as the lime-putty finish. Special finishes too numerous to mention may be obtained by using suitable materials and methods of application.

Plaster should be protected from drying out before setting processes have been completed but after set has taken place it should be dried out rapidly. In hot dry weather, it may be necessary to close all of the openings of the building whereas in cold or rainy weather heat and ventilation may be required. Plaster should be kept from freezing for at least twenty-four hours after application. The changes which occur during the setting of gypsum plasters are described in Art. 9.

Uses. Gypsum plasters are extensively used for interior plastering but they will not withstand long-continued wetting so are not suitable for exterior use as stucco.

Lime Plasters

Classification. Lime for use in plastering is furnished in the form of *quicklime,* which is calcined limestone manufactured as described in Art. 9; and *hydrated lime,* which is calcined lime to which a sufficient amount of water to form the hydroxide has been added at the place of manufacture. Quicklime may be in the form of lump lime or pulverized lime. Hydrated lime is a fine white powder.

Lump lime is divided into two general classes: *calcium lime,* which contains a small percentage of magnesium; and *magnesium lime,* which contains a relatively high percentage of magnesium.

Hydrated lime is divided into two classes: *masons' hydrated lime,* which has a relatively low plasticity; and *finishing lime,* which has a

high plasticity. Either class is suitable for scratch and brown coats, but only finishing lime is suitable for the finish coat. For a more detailed description of the classification of limes, see Art. 9.

Slaking and Mixing. Lump lime is prepared for use by mixing with water to form lime putty or paste. This process is called *slaking* and results in converting the oxides of calcium and magnesium, comprising the lime, into hydroxides. The volume of the lime more than doubles during the process and, in the case of calcium limes, a large amount of heat is generated. Hydrated lime has been slaked at the factory. It is converted into a paste by mixing with water, the increase in volume being very small. For further discussion of the slaking of lime, see Art. 9.

After slaking, lime should be run through a sieve and then be allowed to age for a week or more to make certain that the slaking process is complete and to improve the plasticity and sand-carrying capacity of the lime. A No. 8 sieve should be used for lime to be used for scratch coats and brown coats, and a No. 10 sieve for lime for finishing coats. Sand may be added before or after the putty has aged. Hydrated lime should be allowed to stand for at least twenty-four hours before using.

If lime is used before the slaking process has been entirely completed, the unslaked portions will slake after the plaster has been applied. The expansion which accompanies slaking will break out little chips of plaster forming pits which are often called *lime pops*. Pitting may also be caused by the presence of small particles of overburned lime. Ageing usually prevents pitting from either cause.

Lime putty shrinks a large amount in setting and so cannot be used without mixing other materials with it to reduce this shrinkage. For scratch coats and brown coats sand is used for this purpose and also to reduce the cost. For the finish coat, fine white sand is used or, if a hard, highly polished surface is desired, plaster of Paris or gaging plaster may be used.

The sand for lime plaster should be the same as described for gypsum plasters.

In order to give the plaster sufficient strength, particularly while setting is under way, it is necessary to mix hair or fiber in the scratch coat, and preferably in the brown coat. The hair should be clean long goat or cattle hair free from grease and should be well whipped and soaked before using. Vegetable fiber in place of hair should be well whipped and at least 2 in. long. The hair is worked into the mortar after the slaking of the lime has been completed but before ageing. If the hair is added before the slaking is completed, it may become brittle

and worthless due to the heat generated during the slaking. Hydrated lime fibered at the plant is available.

Mortar may be mixed by hand but machine mixing gives better results. An ordinary concrete mixer may be used but machines especially designed for mortar mixing are preferable.

The time of set of lime mortar may be hastened and the strength increased by the addition of small amounts of portland cement or Keene's cement. The amounts to be added are determined by the desired time of set and strength. If only the hastening of the set is desired gypsum plaster may be used.

Proportions. For convenience, lime plaster is usually proportioned by volume instead of by weight. The proportions are expressed in terms of the proportions of lime paste or putty and sand. This putty may be made by slaking lump lime or from hydrated lime. About 27 lb. of quicklime or about 44 lb. of hydrated lime will make 1 cu. ft. of stiff putty. The sand-carrying capacity of various limes differs greatly; so any proportions which might be given must be approximate. If too little sand is used, the material cost for the mortar is high and the mortar is sticky. If too much sand is used, the cost of materials is low but the labor cost of mixing and spreading is high and the plaster is not durable.

The proportions commonly used for the scratch and the brown coats are:

Scratch coat: One part stiff lime putty to 2 or 2½ parts of sand by volume.

Brown coat: One part of stiff lime putty to 3 or 4 parts of sand by volume.

The amount of hair or fiber in the scratch coat should be about 1 bu. per cu. yd. of sand. If hair is used in the brown coat, ½ bushel per cu. yd. should be sufficient. More sand is used in the brown coat than in the scratch coat to reduce shrinkage cracks.

The proportions used for the different kinds of finish coats are:

White coat: Three parts of stiff lime putty to 1 part of plaster of Paris.

White sand finish: Three parts of stiff lime putty, 3 parts of white sand, 1 part of plaster of Paris.

Brown sand finish: One part stiff lime putty, 3 parts of brown sand, small amount of plaster of Paris.

Application. The method of application of lime plaster is about the same as that of gypsum plaster described earlier in this article. Some difference is caused by the fact that lime mortar is much slower in setting than gypsum mortar. The chemical change which occurs during

setting requires carbon dioxide, which is absorbed from the air. In order that this setting action may be completed it is necessary to postpone the painting of lime-plaster surfaces with oil paint until sufficient time has been allowed for setting. If the plaster is applied to lath the absorption may proceed from the unfinished side but if applied to a solid base at least two months should be allowed before oil paint is applied.

When the scratch coat is firm but not dry, the surface should be scratched with a metal scratcher or a broom to insure a good bond with the brown coat. The brown coat is applied when the scratch coat is dry. It is brought to a true surface by the use of the rod and darby and when this coat is firm but not dry it should be rubbed with a float to eliminate shrinkage cracks and to prepare the surface to receive the finish coat. The finish coat is applied when the brown coat is dry.

The fumes given off by salamanders are injurious to lime, so the use of salamanders should not be permitted.

Special Plasters

Plasters of various compositions may be applied in various ways so as to imitate natural stones. The more common of these are *scagliola*, which is an imitation marble; imitation *caen stone*, which is made to resemble the natural caen stone found in France; imitation *travertine*, which resembles the ornamental limestone of that name. False joints are cut in the imitation caen stone and travertine and filled with Keene's cement so as to give the effect of stone masonry.

Portland Cement Stucco

The following comments concerning portland cement stucco were abstracted from a committee report on that subject which appeared in the 1930 *Proceedings* of the American Concrete Institute, of which W. D. M. Allan was author-chairman.

A majority of stucco failures originate in movements due to lack of rigidity in the structure itself. Successful stucco requires a rigid building designed for stucco; a suitable base to receive the stucco; mortar made of carefully selected materials which are properly proportioned, thoroughly mixed and applied by experienced workmen. There are two general types of construction. One consists of a thin slab of plain concrete which is monolithic with the backing; and the other, a thin reinforced-concrete slab attached to the backing.

The first requirement in stucco design is to keep water from getting back of the stucco. This requires adequate flashing and the use of drip grooves on all molds, caps, and sills. Stucco should be confined to vertical surfaces and should be stopped at a line about 6 in. above grade, preferably at a masonry water table. This is to keep groundwater from getting back of the stucco and to reduce the danger of splashing with the resultant discoloration and disintegration due to frost action. (See Art. 24 for comments on flashing.)

Roof gutters, downspout hangers, and all other supports should be in place before stucco is applied in order to avoid breaks in the surface which would admit water. Concrete masonry, hard-burned clay tile, and hard- or medium-burned clay brick are satisfactory bases. Masonry walls are superior to frame walls because of their rigidity. The masonry surface should be rough, of coarse texture, and free from dust, dirt, or loose particles. Provision should be made for adequate mechanical key where absorption of base is low making it difficult to set a strong suction board. Wood lintels should not be used.

Old monolithic concrete walls can be roughened with a bush hammer and washed clean to provide adequate bond, or they may be washed one or more times with muriatic acid after drenching with water to prevent absorption of the acid. The wall should be thoroughly washed after acid treatment.

New monolithic concrete can be roughened, if necessary, with a heavy wire brush or with other tools; or else a rough surface may be produced by tacking a rough burlap in the forms and removing it as soon as feasible.

Wood-frame structures should be well braced and securely nailed. Studs should be continuous through height of wall. Sheathing is not required and, if used, should be placed horizontally. All lumber should be well seasoned to avoid shrinkage and warping. Insulating boards can be used for sheathing. All sheathing should be covered with waterproof paper, properly lapped at joints, to prevent absorption from stucco of the moisture necessary for proper setting and hardening. Paper-backed metal reinforcing attached directly to studs may be used; or the inside of stucco may be backplastered $\frac{3}{8}$ in. thick or over, between the studs, the reinforcement for the stucco being fastened directly to the studs. The necessity for insulation is greater if sheathing is omitted.

Adequate large-mesh metal or wire-fabric reinforcing held $\frac{3}{8}$ in. away from the base with special furring nails should be used. Wood and metal furring strips weaken the slab and are not satisfactory.

The mixture should be as lean as can be worked. A base coat of 1 sack of cement, 3 cu. ft. of aggregate passing a No. 4 sieve, and 10 lb. of hydrated lime is widely used. Not less than 5 per cent nor more than 10 per cent of aggregate should pass the 100-mesh sieve. Excessive fines or cement increases the shrinkage. The *bulking*, or increase in volume of the aggregate due to moisture, should be taken into account or it should be kept dry. Hair or fiber is used only in the first coat of stucco in backplastered construction. The finish coat should be essentially the same as the base coat.

Three coats of stucco are required on frame structures and on masonry. The bond secured in the first coat is important. This coat should be about $\frac{3}{8}$ in. thick and should be scored to provide bond for the second coat. The first coat should be *dashed* on monolithic concrete. Troweling tends to entrap air between concrete and stucco and to reduce the bond. A dash brush is used with mortar of creamy consistency of 1 part cement and $1\frac{1}{2}$ parts aggregate, thrown on the surface with a strong whipping action. The second coat is about $\frac{3}{8}$ in. thick and straightens the wall. After it has stiffened, it should be smoothed and compacted with a wooden float. The finish coat is of the thickness required by the texture.

After each stucco coat is applied, it should be damp cured for at least two days and allowed to dry for several days. Each coat should be dampened to control suction, but not saturated, before the next is applied. Moisture should be applied frequently in a fine fog spray so the wall does not become dry during the two-day curing period. Proper curing is vital to stucco.

Magnesite Stucco

Composition and Manufacture. Magnesite stucco consists of a dry mixture of magnesium oxide, asbestos, or other inert material, and a mineral pigment to which liquid magnesium chloride is added on the job to form a plastic material which may be applied as a plaster to wood and metal lath or to brick, hollow tile, and other masonry surfaces except gypsum blocks. When the magnesium chloride is added to the magnesium oxide, magnesium oxychloride is formed. This is an effective cementing material.

Magnesium oxide is prepared by calcining magnesite, which is magnesium carbonate, carbon dioxide being driven off during the process. Magnesium chloride in the powdered form may be included with the other dry materials so that it is only necessary to add water to make magnesite stucco ready for use. Various brands of magnesite stucco are on the market. It appears to be declining in use.

Ornamental Plastering

Ornamental plastering includes moldings, cornices, panels, decorative ceilings, rosettes, etc., made of plaster or similar material and placed in the interior of buildings.

The base for moldings of small projection is built up solid with the same material as that used for the brown coat. It is built up to approximately the shape of the molding, making sure that there is clearance enough to allow for the finish coat, which is composed of lime putty gaged with plaster of Paris. The finish coat is applied to this base and is cut to the desired profile by means of a sheet-metal templet operating on guides. The finish coat can not be cut with sharp outlines in one operation but must be gone over several times, the low places being filled in with mortar each time.

For larger moldings the base is built up of metal lath supported on braces.

The moldings and similar ornamental plastering are placed before the finish coat on the remainder of the walls and ceiling because the guides could not be placed on the finish coat of the walls and ceiling without marring it. Parts of moldings, such as internal and external miters which can not be run with templets, must be formed by hand, or they may be cast and placed in position before the moldings are run. Parts of moldings such as dentils and brackets may be cast separately and *stuck* in place after moldings are run.

Ornaments which can not be run are cast in gelatine molds, or they may be purchased from firms which make a specialty of this kind of work. They are made of plaster of Paris or of a special mixture consisting of such materials as whiting, glue, paper pulp, and wood fiber. Such ornaments are stuck in place by means of plaster of Paris.

REFERENCES

1. Specifications of the American Society for Testing Materials for Gypsum Plasters, Keene's Cement, Sand for Use in Plaster, and Gypsum Lath.
2. "Sweet's Catalog File," F. W. Dodge Corporation.

CHAPTER XII

HEAT INSULATION AND ACOUSTICS

ARTICLE 76. WALL, CEILING, AND ROOF INSULATION

General Discussion. There has been an increasing interest during recent years in making the air in occupied buildings more comfortable and healthful and in conditioning the air in manufacturing buildings to suit the manufacturing processes. There has also been interest in reducing the operating costs involved in such improvements. Two important factors in bringing about these conditions are the temperature and the humidity of the air in the buildings. Both of these factors are closely associated with the construction of the building. In winter, the problem is largely one of providing additional heat and additional humidity, while, in summer, these may be present in excessive amounts. There is a considerable operating cost involved in increasing or decreasing the temperature of the inside air. Usually the savings in this cost which can be brought about by proper design and construction, including insulation, will much more than justify the additional expenditure involved. The direct cost of increasing humidity is not large, but humidities of 35 to 40 per cent and over, which are often maintained, may cause condensation in the outside walls and the roof or ceiling of the top story which can only be avoided by appropriate types of construction. Decreasing the humidity, as may be desirable in many parts of the country during the summer, is not as easily and cheaply accomplished as increasing the humidity, but this does not require any special consideration so far as the construction of buildings is concerned, except where unusually low humidities or temperatures are employed.

Heat Losses. Heat passes from one side of the walls and roof of a building to the other in the following ways:

1. By *air infiltration* or leakage through cracks and other open spaces. The volume of air entering a building is offset by an equal volume leaving the building. Since the temperature of the two volumes would normally be different, there is a transfer of heat with the air change.
2. By *transmission* through the walls, windows, doors, and roofs.

Air infiltration is minimized by good construction which reduces or eliminates cracks and other openings through the walls, around cor-

nices, along the sills on foundation walls, and through the roof construction; by the proper design, construction, and installation of doors and sash and their frames; by calking between frames and surrounding masonry; by covering the sheathing of frame walls with a good quality of building paper with tight joints; and by plaster surfaces on masonry walls. Air infiltration through an unplastered 8-in. brick wall may be from fifty to one hundred times as great as through the same wall after plastering. The effectiveness of storm sash depends upon how tightly they fit and is relatively higher on windows which are not weather-stripped.

Due to the " chimney effect " in tall buildings, the tendency for air infiltration at the lower stories, and for the corresponding outward movement in the upper stories, is so large as to require that special provisions be made to reduce this effect. These provisions consist of closing, with doors or by other means, all openings from floor to floor such as stairways and elevator shafts. This is also a necessary fire-protection measure. Heat losses by air infiltration increase rapidly as the wind velocity increases and may exceed the losses due to the difference in temperatures inside and outside a building.

Heat is transmitted through walls and roofs in three ways:

1. By *conduction* from molecule to molecule of the wall material and, to a certain extent, of the air in open spaces in the wall.

2. By *convection* by air currents, which circulate in open spaces within the wall or roof construction and which absorb heat as they pass upward over a warm boundary surface of the air space and release heat as they pass downward over a cold boundary surface of that space. The circulation is due to the decrease in density of air which accompanies increase in temperature.

3. By *radiation,* which is the process by which energy, called *radiant energy,* is transmitted from one body or surface to another body or surface by electromagnetic waves.

Heat passes through a solid wall entirely by conduction, but if there is an air space inside the wall it will cross this space by radiation, convection, and conduction. The resistance which a given homogeneous material offers to the passage of heat increases with the thickness, but not in direct proportion, and decreases as the density and the moisture content increase. The resistance of an air space, such as a stud space in a frame wall or a cell space in a hollow tile wall, to the passage of heat by radiation is independent of the width of the space but is greatly affected by the nature of the boundary surfaces, being low for the surfaces of ordinary building materials but very high for bright metallic surfaces. The resistance by an air space to the passage

of heat by convection is practically independent of the width of the space as long as this width exceeds $\frac{3}{4}$ in., but it decreases very rapidly as the width decreases below $\frac{3}{4}$ in. More than half the heat conducted through an air space over $\frac{3}{4}$ in. wide bounded by ordinary materials is radiant heat.

The conductivity of glass is high and there is practically no loss of radiant energy in passing through glass. For these reasons, the heat loss through windows is large during cold weather, and the inside temperature on summer days is increased considerably by the radiant energy of the sun which passes through the window glass. The conductivity of the window area may be decreased by double-glazing, which is placing in a sash two panes of glass separated by an air space of about $\frac{1}{2}$ in. which is hermetically sealed around the edges. The air which is sealed in is dehydrated to avoid condensation and the seal prevents the infiltration of dirt. The heat loss through window areas and doors may also be reduced by the use of removable, tight-fitting *storm sash* or *storm doors.*

About three-fourths of the radiant energy of the sun can be excluded by awnings or by properly adjusted outside Venetian blinds or shutters. Inside Venetian blinds and shades are much less effective. Only a small percentage of the radiant energy of the sun can be reflected outward after it has once passed through a window. An insect screen is available with the horizontal wires replaced with metal strips and the vertical wires about $\frac{1}{2}$ in. apart to form a Venetian blind with miniature slats. This would seem to have possibilities for excluding radiant energy from the sun.

The radiant energy from the sun increases attic temperatures as much as 60 degrees above the outside air temperatures. During the summer, this accumulation of heat and the high temperatures cause a considerable increase in the inside air temperatures. This effect is reduced by ceiling insulation or insulation on the under side of the roof. It can also be reduced by ample natural ventilation of the attic but much more effectively by an attic fan with large capacity, discharging outdoors.

Condensation. The amount of water vapor which air can contain increases with the temperature of the air. The ratio of the amount actually present to the maximum amount which can be present at that temperature is called the *relative humidity,* or, simply, the *humidity.* This is expressed in percentage. As the temperature of air containing a given amount of water vapor falls, the relative humidity rises until the saturation or *dew-point temperature* is reached and some of the vapor is condensed. This condensation may occur on cold interior wall

surfaces and be apparent; but the water vapor tends to pass through the walls and, since the interior of a wall becomes progressively colder as the outside is approached, a temperature may be reached at which the vapor will condense within the wall. The conditions which are favorable for this action are an inside humidity of 35 or 40 per cent and higher and a long-continued cold outside temperature. The amount of water which condenses gradually increases and, if the temperature where the water collects is below freezing, ice will form. If porous insulation is present, it will accumulate water as ice and largely lose its effectiveness. The ice will melt when the outside temperature rises sufficiently. Condensation may also occur in insulation over the ceiling of the top story, or on the under side of the roof sheathing, particularly around the points of protruding roofing nails. The condensation which forms in the walls, ceiling, or roof construction may come through the finished wall and ceiling surfaces and spoil the decorations, disintegrate the plaster, cause any wood present to swell with resultant cracking, cause paint on exterior wood surfaces to peel off, and damage a building in other ways. These effects are sometimes wrongly attributed to leaking walls and roofs. In wood construction, the wall may be so tightly sealed with sheathing paper that evaporation occurs very slowly. This may cause the studs and sheathing to decay. Insulation may make conditions worse by causing the outer portions of a wall to be colder, and porous insulation accumulates the water. Some of the higher grades of sheathing paper used on stud walls retard or prevent the escape of water vapor from the walls and increase the condensation effect.

To remedy condensation of this type, avoid high humidities during long periods of low temperatures; place a *vapor barrier* or *seal* under the lath in stud walls and on the ceiling joists of the top story and use a sheathing paper which is sufficiently airtight but not an effective vapor barrier; place a vapor seal under the lath on furred masonry walls; place a vapor seal under the insulation of wood or concrete roof decks, if insulation is used, and ventilate attic spaces. A glossy-surfaced tar paper is considered a good vapor seal for use under lath. It must be lapped and tightly fastened at all joints. The longitudinal joints should be over the studs or joists, and the paper should extend from the floor to the ceiling without end joints in the paper. Slaters' felt is considered a satisfactory sheathing paper. On roof decks, a two-ply seal should be made of saturated felt applied by mopping with hot asphalt or roofing pitch.

Some of the rigid insulating materials are coated with bituminous material or are encased in bituminous paper to exclude water vapor;

many insulating quilts have so-called vaporproof paper coverings; and mineral wool batts are available with vaporproof backs which are placed next to the lath in wood stud walls. These are not regarded as high types of vapor barriers.

Types of Insulating Materials. Insulating materials may be divided into two general classes according to the way they function. In the first group may be included all those low-density, porous or fibrous materials with low conductivity or high resistance to the passage of heat, whose effectiveness is due to the minute air spaces of which they are largely composed. This group includes three general types of insulating materials as follows: *rigid* or board insulation; *flexible* or quilt, blanket, and batt insulation; and *fill* insulation.

The second group of insulation materials includes those of the *reflective* type which is used to form boundaries of air spaces and whose insulating value lies in its effectiveness in reflecting radiant energy.

The rigid, flexible, and fill insulators consist of wood, cane, and other vegetable fibers, mineral wool, cork, hair felt, expanded mica, or light granular materials. They owe their insulating properties to the minute air spaces which they contain. The insulating value for equal thicknesses is about the same for all these materials. It is approximately equal to the insulating value of 3 in. of wood, 17 in. of glass, 31 in. of brickwork, and 40 in. of concrete.

Reflective insulation consists of some form of sheet metal, metal foil, or a metallic coating which is made very thin because its effectiveness is practically independent of the thickness. The most effective insulation of this type will reflect about 95 per cent of the radiant energy which strikes its surface. Since a large proportion of the heat which passes through an insulated wall is due to radiant energy, reflective insulation can be very effective. According to Rowley:[2]

An air space lined with ordinary material is equivalent to approximately 0.3 inch of good insulating material, and the same space lined on both surfaces with material having a low emissivity coefficient (high reflective properties) is equivalent to about 0.8 inch of an insulating material; thus the addition of foil is equivalent to 0.5 inch of insulation.

The air spaces in walls and between the top-story ceiling and the roof are sometimes considered as having a high insulating value because the conductivity of still or dead air is very low. This is not "dead," but is constantly circulating and therefore transmits heat by convection.

Rigid Insulation. Fiber boards, described in Art. 62, are used for insulating purposes. To be effective, the fibers are not highly compressed as in the hard boards. Moisture and water vapor are partially

excluded from some of the fiber boards if the boards are coated with asphalt or encased in a bituminous waterproof paper. For increased insulating value, fiber and plaster boards are available with aluminum-foil coating on one surface to serve as reflective insulation. Another form of rigid insulation is cork board made of pressed cork. It is available in thicknesses up to 6 in. Some forms of rigid insulation serve the dual purposes of insulation and sheathing or insulation and lath. The common thickness for sheathing is 1 in., but any desired thickness may be secured.

Flexible Insulation. This type of insulation may be in the form of *quilts* or *blankets* and *batts*, often spelled *bats*. The quilts and blankets consist of a fibrous material such as treated wood fiber, hair felt, flax fiber, eel grass, or shredded paper stitched between sheets of waterproof paper to form a flexible material available in various thicknesses up to 1 in.

Another form of flexible insulation is made from *mineral* or *rock wool*, formed by blowing molten rock into fibrous form by steam under pressure. This produces a fluffy, non-combustible product weighing about 6 lb. per cu. ft. It is usually furnished in batts 15 by 24 or 48 in., to fit between studs and ceiling joists spaced 16 in. center to center. The thickness is commonly about 4 in. to fill the space completely between 2- by 4-in. studs, but batts 2 in. thick are available. Batts are furnished plain or with a waterproof paper cemented to the back and projecting about 2 in. on each side to provide *nailing flanges*, which lap over the studs or joists to which they are nailed and form a seal. This paper is supposed to serve as a vapor barrier or seal, but to be effective the end joints must be tight. It is better practice to provide an additional vapor barrier, as previously described, over the batt insulation, after it is in place, and under the lath. Mineral-wool insulation is also furnished in roll form and as fill insulation, as described in the paragraph under that heading. *Glass wool* is a fibrous glass insulating material similar to mineral wool. It is available in batt, blanket, and fill form.

Fill Insulation. This material consists of granulated rock wool in the form of nodules or pellets, granulated cork, expanded mica, and other material which is blown through large tubes or dumped into open spaces in the walls and ceilings of buildings, such as the stud space in frame walls and the ceiling joist space. Fibrous mineral wool and glass wool are also furnished in loose form for packing by hand into open spaces.

Reflective Insulation. Reflective insulation is placed in air spaces and functions by reflecting a large percentage of the radiant energy which strikes it. The materials used for reflective insulation are very

thin tin plate, copper or aluminum sheets, or aluminum foil on the surface of rigid fiber or plaster boards. The effect of the degree of brightness and cleanness of the reflecting surface on the effectiveness of reflective insulation is still being debated. A common form of reflective insulation is aluminum foil mounted on asphalt-impregnated kraft paper, the strength of which may be increased by the use of jute netting. This material is used for lining air spaces or as curtains to increase the number of air spaces in a given overall space. To be effective, the edges of such curtains must be tightly sealed.

Methods of Installation. *Rigid insulation* can be used as sheathing on the outside of wood studs, as shown in Fig. 217*a*; as building board without plaster on the inside of wood studs, as shown in Fig. 217*b*; and on the lower side of ceiling joists or rafters. It may also be used as lath to receive plaster on the inside of wood studs, as shown in Fig. 217*c*; and on the lower side of ceiling joists. When used with masonry walls, it is nailed to furring strips, as shown in Fig. 217*d*. It may be exposed; it may serve as a plaster base, as shown in Fig. 217*e*; or it may be covered with lath and plaster, with furring strips between the insulation and the lath and on top of the other furring strips or at right angles to them, as shown in Fig. 217*f*.

Rigid insulation may be used on wood and concrete roof decks under built-up roofing, as illustrated in Fig. 217*g* and *h*. Wood decks are first covered with one or two layers of rosin-sized building paper lapped at the joints and securely tacked down. This paper keeps asphalt from running through the cracks between the roofing boards. Over this paper or directly on concrete roofs a layer of asphalt-saturated felt is mopped with hot asphalt or roofing pitch. This layer serves as a temporary roofing. If there is to be considerable vapor in the room below, another layer of asphalt-saturated felt is applied by mopping with hot asphalt or roofing pitch to improve the vapor seal. The insulation is applied by coating the surface of the felt with hot asphalt or roofing pitch just before placing the insulation. Each board is bedded in the hot asphalt or roofing pitch. As many layers of insulation as desired are placed in this way. Finally, with staggered joints, a built-up roofing is applied by mopping the first ply to the top of the top layer of insulation. Slate and tile wearing surfaces can be placed on top of the built-up roofing if desired.

In placing the insulation, precautions must be taken to protect the insulation from rain or other moisture by placing, at one time, only such an area as can be covered in a short period, and never leaving the insulation unprotected over night. Also, it is good practice to localize the effect of any leakage which may occur, and to provide a place

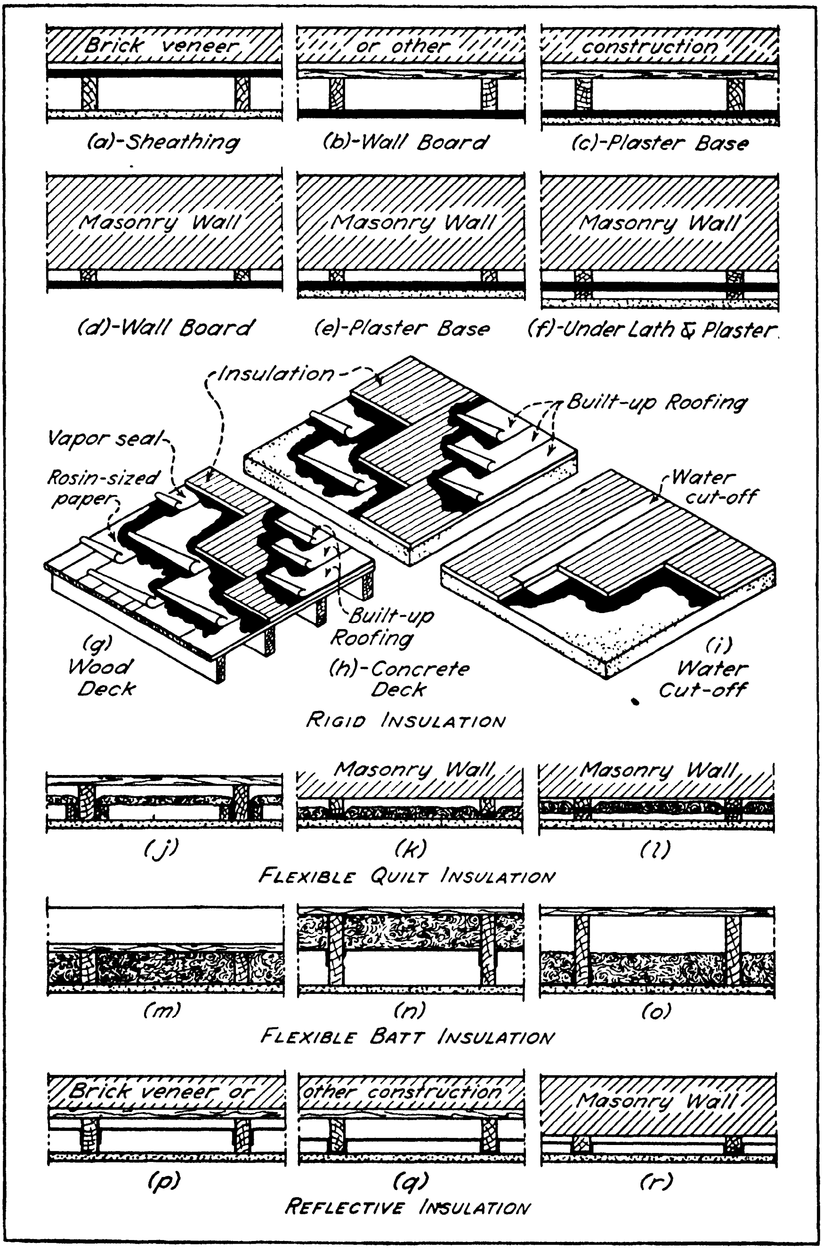


FIG. 217. Installation of Heat Insulation

where work can be stopped, by dividing the roof into about 30-ft. squares with *water cutoffs*. These are made by inserting a 16-in. strip of asphalt-saturated felt at joints, as shown in Fig. 217*i*, the strip being tightly cemented to the surface below the insulation and to the insulation itself. Other cutoffs should be located parallel to the parapet walls and about 2 ft. from them. All interruptions in work should occur at water-stops, and the insulation which has been placed should be protected temporarily with at least one ply of the built-up roofing extending to water-stops on all sides. Insulation laid on wood decks sloping more than 3 in. to the foot should be nailed to the deck. Insulation applied in this manner should not be used on concrete decks with such slopes.

Flexible insulation is installed in open spaces in the wall, ceiling, or roof construction where it will not be subjected to loads for it is easily compressible. Quilts or blankets are installed between the studs and ceiling joists in frame construction or between furring strips on masonry walls, as illustrated in Fig. 217*j*, *k*, and *l*. More than one layer of quilt, together or separated, can be used if desired. Quilt insulation divides the space it occupies into two or more air spaces. To be efficient, the insulation should be so fastened at the sides and ends that there will be no air leakage between spaces. Batts are inserted between studs, as shown in Fig. 217*m*. If they are provided with waterproof back and with nailing flanges, they are lapped over the studs, as shown. If the studs, joists, or rafters are deeper than the thickness of the batts, the nailing flanges are nailed to the sides of these members, as shown in Fig. 217*n*. Ceilings are insulated, as shown in Fig. 217*o*, or the batts may be inserted from below, as shown in Fig. 217*n*, before the lath are placed.

Fill insulation is installed by pouring the loose granulated or nodulated form into open spaces between the studs of stud walls and between ceiling joists or is installed by blowing this material into place through large flexible tubes using low air pressure. The fibrous mineral wool and glass wool is available in bulk form. It is packed by hand into the space between studs and joists. Great care is necessary to insure the complete filling of stud spaces.

Reflective insulation is applied between studs, joists, or rafters, as shown in Fig. 217*p*. Nailing strips may be used to hold it more tightly. Some forms may be installed by lapping over the studs, as shown in Fig. 217*q*, or by inserting between furring strips on masonry walls, as shown in Fig. 217*r*. This insulation divides the space into two or more air spaces. It is important for the most effective results that the insulation be fastened at the sides, top, and bottom, and at all laps so that there will be no circulation of air between the two spaces.

ARTICLE 77. ACOUSTICS

General Comments. Improvements in construction during recent years have often resulted in buildings with poorer acoustical properties owing to the more rigid materials and construction used; while, on the other hand, radios and radio broadcasting, sound motion pictures, the increased use of mechanical office equipment, the increase in street noise due to the automobile, and many other factors have emphasized the importance of improvement in acoustical conditions. Largely because of its increasing importance, knowledge in the field of architectural acoustics has been developed to a stage where the necessary acoustical treatment can be determined when the plans and specifications of a building are being prepared. By this procedure, the construction of buildings with good acoustics can be assured and the embarrassment and inconvenience of remedying defective acoustical conditions while a building is in use, usually at much greater cost, can be avoided. The various acoustical considerations which enter into the design of buildings are considered briefly in the following paragraphs so that the problems involved will be appreciated, but no effort is made to present material which can be used in the solution of specific problems. To secure good results, specialized advice is usually required.

The more important acoustical factors which should be given consideration when the site for a building is being selected and in the design of the building itself are:

1. Reverberations within each room of sound originating in that room and the possibility of disturbing echoes.

2. Outside noises or objectionable sounds within a room due to sounds originating outdoors or in other parts of the building.

Reverberation. If a sound, of such an extremely short duration that it can be called instantaneous, is produced in a room whose interior wall surfaces reflect all of the sound which reaches them, which of course is impossible, the sound which reaches any point directly from the sound source will be reinforced by successive echoes from the interior surfaces. Those echoes will continue indefinitely and undiminished in intensity because no sound is absorbed by the walls. The time required for the sound to build up to its maximum intensity will depend upon the time required for the sound waves to pass back and forth between the reflecting surfaces, and will therefore increase with the size of the room. However, this period will be very short, in any case, because the velocity of sound in air is about 1100 ft. per second. If the sound is produced steadily for a definite period, rather than being instantaneous, the intensity at any point will continue to be built up

by echoes as long as the sound is produced and very soon after the sound stops will reach a maximum intensity which will continue indefinitely.

The other extreme is represented by another impossible case of a room with interior surfaces which absorb all of the sound which strikes them so that there are no echoes. The sound conditions in this room would be the same as outdoors, with no reflecting surfaces present. If an instantaneous sound is produced in such a room, the sound intensity at a given point will be determined by the sound which reaches the point directly and will not be built up by echoes, for there are no surfaces present which will produce echoes. The sound at the point will be of instantaneous duration. If the sound source is continued with constant intensity, the sound at the point will continue with constant but lower intensity for the same length of time, but will lag slightly behind the source because of the brief period required for the sound to pass from the source to the point.

Actual rooms, of course, lie between these two extremes. The sound intensity reached at any point and the duration of the sound after the source ceases are determined by the sound-reflecting efficiency of the surfaces in the room. The surfaces to be considered include not only the interior surfaces of the room itself but also the furniture, the curtains, the people present, and other contents of the room. The prolongation of the sound after the source ceases is called *reverberation.* A quantitative measure of reverberation was established by W. C. Sabine who defined the *reverberation time* as the time required for a sound to decrease to one-millionth of its original intensity after stopping the source. By experiment, he established the relationship

$$T = 0.05 \frac{V}{A}$$

in which T is the reverberation time in seconds, V is the volume of the room in cubic feet, and A is the total of the absorption units in the room. An *absorption unit* is absorption equal to that of a square foot of an open window which is considered as 100 per cent efficient in absorbing sound, although it really transmits the sound outward instead of absorbing it. For example, if a square foot of surface absorbs one-half of the sound energy which strikes it, that square foot will represent one-half unit of absorption and its *absorption coefficient* will be 0.50.

The reverberation time of a room which has been constructed can be determined, of course, by experiment. The formula is used for predicting the reverberation time of rooms which are being planned. The

reverberation time of the room with perfect sound-reflecting surfaces (considered above) is infinity while that of the room with perfect sound-absorbing surfaces is zero. Factors affecting the most desirable reverberation time for a given room are considered in the next paragraph.

Since echoes reinforce the sound at a point, they build up the sound intensity; but, since each echo of a spoken syllable or musical tone which reaches that point lags slightly behind the preceding echo, the sound at the point becomes less distinct as the number of echoes reaching the point increases. Therefore, the *intensity* of sound at a point in a room increases and the *distinctness* decreases as the reverberation time increases. The most desirable or *optimum reverberation time* for any room can be determined only by obtaining the opinions of persons using that room. The ear is accustomed to some reverberation; consequently, a room with a very short reverberation time seems *dead* and unnatural, because of the lack of echoes, and the sound intensity is low. The optimum reverberation time is longer for music than for speech, and increases as the size of the room increases. It varies from about one second for small rooms to about two seconds for large auditoriums. These values have been established by measuring the reverberation times in rooms which are considered to have desirable acoustical properties and in auditoriums which are recognized as being superior in this respect. As stated by Davis:[9]

> Excessive reverberation is the most serious defect where speech is concerned: insufficient reverberation is unacceptable for music.

The time of reverberation of a given room may be controlled by using special acoustical materials with high absorption coefficients. These materials are available in a great variety of forms such as acoustical plaster and tiles with porous surfaces; fiber boards whose coefficients are increased by perforating with closely spaced holes; hair felt, mineral wool, and other fibrous materials whose appearance is improved by covering with canvas, burlap, or other open-textured cloths or with very thin sheets of metal perforated with closely spaced holes. These materials absorb sound by dissipating the sound energy in the pores, by vibrating the fibrous materials, and by yielding in compression under the impact of sound waves. They are commonly made in tile form for attaching to wall and ceiling surfaces. Their effectiveness may be reduced if porous surfaces are closed with paint, but perforated surfaces can be painted. As has been mentioned, carpets, draperies, and upholstery have high absorption coefficients, and an audience is very effective in absorbing sound. Some idea of the relative effectiveness of various materials can be obtained from the following table of

absorption coefficients for a frequency of 512 cycles per second which is a medium value, the coefficients varying somewhat with the frequency. From this table it is seen that hair felt covered with burlap absorbs about three-quarters as much sound as is absorbed, or transmitted outward, by an open window, whereas a plastered hollow-tile partition absorbs only one-fiftieth as much sound as an open window. The data for this table were obtained from references given at the end of this chapter, from which more complete information can be secured.

ABSORPTION COEFFICIENTS

(For Frequency of 512 Cycles per Second)

Material	Coefficient
Open window	1.00
Audience	0.96
Hair felt covered with burlap	0.74
Perforated cane fiber board 1¼ in. thick	0.70
Corkboard 1 in. thick	0.30
Acoustical plaster	0.15 to 0.30
Carpet 0.4 in. thick on concrete	0.21
Unpainted brick wall 18 in. thick	0.08
Linoleum	0.10
Wood sheathing	0.10
Wood floor	0.03 to 0.08
Varnished wood	0.03 to 0.08
Lime plaster on wood lath	0.034
Ceramic tile	0.029
Gypsum plaster on hollow tile	0.020
Audience, per person	4.7 units

Disturbing Echoes. An important consideration in the acoustic design of a room is the position and shape of the interior surfaces. These should be arranged so as to avoid concentrated reflections of sound that will produce disturbing echoes. Plane walls and rectangular shape are preferred because curved walls and domes prove to be faulty. In some modern auditoriums, convex surfaces have been used to diverge sound. As an aid in anticipating the effect of the reflection from the surfaces, the designer may make a geometrical study of the main sections of the room, using the usual laws of optics. If any marked concentrations of the sound after reflection are found, the surfaces should be changed to reduce these effects. Some auditoriums have been found so faulty in this respect that they could not be used with any satisfaction until the offending surfaces were modified. These echoes occur usually after one or two reflections of sound. The later reflections and echoes create the reverberation, which is the most usual acoustic consideration in auditoriums.

Office Quieting. The quieting of offices presents one of the most frequent acoustic problems in buildings. The solution involves a reduction of loudness of sound rather than a control of reverberation as in larger rooms. The usual procedure is to install sound-absorbing materials on the ceiling, but according to modern theory it appears to be more efficient if the installation is made along the edges of the room. A lined carpet helps in the reduction of loudness.

External and Internal Noises. This discussion is based largely on work done at the National Bureau of Standards and presented in Report BMS17 entitled "Sound Insulation of Wall and Floor Constructions," by V. L. Chrisler.[10]

When the use of a building is such that noise is objectionable, this factor should be given consideration in the selection of the site. This is particularly important in the case of hospitals and schools. If it is necessary to locate such a building on a noisy street, the windows should be eliminated and artificial illumination provided, or double windows should be used and precautions taken to eliminate leakage of sound around the windows. In either case, mechanical ventilation is required. Buildings located near railways, subways, elevated lines, or highway traffic arteries often require special treatment to prevent the transmission of vibration through the foundation into the building.

It may be desirable to locate rooms which should be quiet on interior courts away from street noises, but if this is done no room in which excessive noises are produced should be located on the court. Also in residences, the sleeping rooms can be located on the side away from the prevalent sources of noise. Mechanical equipment should not be located above rooms where quiet is desired.

Noise may enter a building in the following ways:

1. By transmission of *air-borne sounds* through openings, such as windows or doors, cracks around doors, windows, water pipes, conduits, ducts of ventilating system, and in other ways.

2. By transmission of structural vibrations or *structure-borne sounds* from one part of a building to another. Such sounds, with rare exceptions, finally reach the ear through the air.

3. By direct transmission through various portions of the structure itself, which act as diaphragms and are set in motion by the sound waves striking them.

Air-borne sounds are lowered by reducing the openings to a minimum and even eliminating windows entirely. The amount of sound admitted through a closed window of a room may be many times that admitted through the walls, ceiling, and doors and that admitted by a closed door may be as much as is admitted by the remainder of the enclosing struc-

ture of a room except the window. The amount of sound admitted through a window or door only partly opened is many times that admitted by a closed window. These qualitative relationships emphasize the importance of windows in noise control considerations. Most of the noise from ventilating ducts can be eliminated by inserting acoustic filters.

Sounds transmitted by structural vibrations may be reduced by giving special consideration to this factor when designing the building and in selecting materials which do not transmit vibrations readily.

The weight of a homogeneous wall per unit of area is the most important factor in determining its sound-insulation efficiency. The kind of material and the way it is held in position are of secondary importance. Because of its lightness, fiber board is not an effective sound insulator. The sound-insulating value of a given material does not increase directly with the thickness or weight per unit of area, but as the logarithm of this weight; so a high degree of sound insulation can not be secured with a homogeneous wall unless it is excessively thick.

The insulating value of a wall of a given weight can be increased considerably by dividing the wall into two or more layers. In an ordinary lath and plaster partition, with wood studs to which the lath are fastened, most of the sound is transmitted directly through the studs and only a small portion indirectly from one layer of lath and plaster across the air space to the other layer. Stiff studs transmit less sound than flexible studs but hard strong plaster is a poorer insulator than soft weak plaster which unfortunately is not sufficiently durable for use. A partition constructed of gypsum lath fastened to the studs with resilient metal clips is a more effective insulator than one in which the lath are nailed directly to the studs.

Staggered studs may be used, with each plaster layer fastened to different sets of alternate studs. This prevents the transmission of sound directly through the studs, but a considerable amount of sound is transmitted indirectly by the studs through the top and bottom plates to which they are attached. The sound-insulating value of a stud partition may be decreased, rather than increased, by using a filling material between the studs. However, if the filling material is elastic and exerts pressure against the layers of lath and plaster, it may improve the sound-insulating properties of the partition.

A double or cavity masonry wall is more effective in sound insulation than a single wall, but fillers placed in the intervening space seem to have little value. Partitions constructed of 3- or 4-in. hollow tile with plaster applied directly to the tile are too light to give satisfactory

sound insulation for most cases. If furring strips are fastened to the tile, a waterproof paper is placed over the furring strips to cut off any possible contact of the plaster with the tile, and lath and plaster are then applied to the furring strips, the insulating properties of the partition are increased considerably. Experiments indicate that the method used in fastening the furring strips to the tile is of little importance.

The sound insulation of a masonry floor can be improved by using a *floating floor* of wood and a suspended ceiling. The method of attaching the nailing strips seems to be of little importance, but rigid hangers should not be used for the suspended ceiling. Flexible supports such as springs or wires should be satisfactory.

As summarized in the Report:

From the above discussion, it is evident that the best form of sound insulation for masonry would have the following construction. What might be called the core of the building would be built in the customary manner, that is, with walls and floors of masonry. From this point the procedure would be different. The room would be formed of rough masonry and inside of these, finished surfaces would be applied. Instead of plastering on the masonry to form the wall and ceiling surfaces, these surfaces would be furred out so that the finished plaster surfaces would not be in direct contact with the masonry. Likewise, the floor would be of the *floating* type. In other words, we might picture it as a box within a box, the inner box to be attached to the outer one at as few points as possible, with these connections no more rigid than absolutely necessary.

Impact noises caused by walking or moving furniture or by a direct transfer of vibration from machines and musical instruments, such as pianos and radios, form another class of noise which is more difficult to insulate than air-borne noise. A machine often sounds as noisy in the room below as in the room where it is located. A so-called floating floor is sometimes built by laying a rough sub-floor on wood joists and over this placing a layer of fiber board which supports a finished wood floor nailed through the fiber board to the rough floor. Experiments show that the fiber board, laid in this manner, has no sound-insulating effect. A floor constructed in a similar manner to that which has just been described, but with nailing strips above the fiber board to receive the nails holding the finished flooring, is much more effective. The method of fastening the nailing strips is not of great importance. They can be nailed every 3 or 4 ft. or can be held in position by straps, springs, or small metal chains containing felt. Conversation is not audible through such a floor, but it is not effective in reducing impact noises such as those caused by footsteps.

Floors constructed with separate wood joists for the floor and ceiling below did not give experimental results quite as good as the floating floor. A floating floor added to this construction was very satisfactory so far as air-borne noises were concerned, but was not as satisfactory in reducing impact noises.

Impacts applied directly to a masonry floor were practically as large in the room below as in the room where they were applied. A floating floor resulted in decided improvement and a suspended ceiling gave still further improvement. The reduction in air-borne noise was better than for impact noise, but the latter was much less than for a masonry slab alone. The masonry construction with a floating floor and a suspended ceiling gave better results than a wood floating floor with floor and ceiling joists separated as has been described.

The noise level in a room can be reduced by increasing the total absorption units in the room, but the reduction which can be accomplished in this manner is not large. A much greater reduction can usually be obtained at less cost by increasing the sound insulation of the walls, ceiling, and floors of the room. Absorbent materials may be necessary to keep down the noise level resulting from noises originating in the room. Absorbent materials prevent corridors from acting as speaking tubes transmitting sound from one room to another when the doors are open.

The masking effect due to other noises is important. If a room is located in a quiet area, it may be possible to hear sounds clearly from an adjoining room, but if the room is located where the sound level is high, very little may be heard.

Air-borne machinery noises are usually much smaller than those caused by the vibration of the foundation or other support for the machinery. The noise due to the vibration of the support can be reduced by placing machines on layers of cork, asbestos, rubber, or felt, and, in some cases, by mounting them on springs.

Experiment shows that the response of the ear to sound energy is approximately proportional to the logarithm of that energy. That is, energies proportional to 10, 100, and 1000 will produce in the ear effects proportional to 1, 2, and 3, respectively. A system of measurement based on this relationship has established the *decibel* as the unit for measuring sound intensity. It is approximately the smallest change in energy that the average ear can detect. Some idea of the magnitude of this unit can be formed from the following: the rustle of leaves has an intensity of about 10 decibels; an average whisper 4 ft. away, about 20; the usual range of speech in conversation, from 35 to 65; stenographic room, 70; loud automobile horn 23 ft. away, 100; and the thresh-

old of painful sounds representing the ear's limit of endurance, 130. Sound intensities are reduced by amounts varying from 30 to 50 decibels by types of wall, partition, and floor construction in common use, but reductions exceeding 75 decibels have been obtained with specially constructed floors. Transmission losses for many types of construction are given in the Report on which this discussion is based.[10]

The sound-insulation value of windows and doors, as well as other aspects of this general problem has been investigated by the Department of Scientific and Industrial Research in London and reported in "The Reduction of Noise in Buildings,"[11] on which the following comments are based.

Because of its light weight, glass is not an efficient sound-insulating material, and, if windows do not close tightly, much sound may be transmitted by air paths. The insulation obtainable with single windows is limited, even if exceptionally thick glass is used. When a high degree of insulation is required, double windows must be used and the windows must normally be tightly closed. Good sound insulation of external walls, therefore, often necessitates the use of double windows with artificial ventilation. The panes should be in separate frames and the space between panes should be at least 2 in. for ¼-in. glass, and 4 in. for single-strength glass.

To give good sound insulation, a single door must fit tightly and be heavy. A ⅛-in. crack around a wood door 2 in. thick would admit four times as much sound of medium frequencies as the door itself. Felt, rubber, or metal strips around the jambs and head are desirable. Also, conditions can be improved by some form of "draft excluder" at the sill, such as a threshold or the "trigger bottom" mentioned in Art. 78. Considerable sound may pass through an uncovered keyhole and so latches and locks without keyholes extending through the door are desirable. Even where single doors are very heavy or of special composite construction, it will often be found that double doors are the most satisfactory means for obtaining a high degree of insulation.

REFERENCES

1. TREESDALE, L. V.: "Condensation Problems in Modern Buildings," Forest Products Laboratory, 1939; also Circular 37, Engineering Experiment Station, University of Illinois, Paper Presented at the Second Conference on Air Conditioning, 1939.

2. ROWLEY, FRANK B.: "Climate and Housing," *Sigma Xi Quarterly*, Vol. 27, No. 3.

3. "Heating, Ventilating and Air Conditioning Guide," American Society of Heating and Ventilating Engineers, published annually.

4. "Sweet's Catalog File," F. W. Dodge Corporation, published annually.

5. WATSON, F. R.: "Acoustics of Buildings," 2nd Ed., John Wiley & Sons, 1923.

6. KNUDSEN, V. O.: "Architectural Acoustics, John Wiley & Sons, 1932.

7. OLSON, HARRY F., and FRANK MASSA: "Applied Acoustics," P. Blakiston's Sons and Co., 1934.

8. STEWART, GEORGE WALTER, and ROBERT BRUCE LINDSAY: "Acoustics," D. Van Nostrand Co., 1930.

9. DAVIS, A. H.: "Modern Acoustics," The Macmillan Co., 1934.

10. CHRISLER, V. L.: "Sound Insulation of Wall and Floor Constructions," Report BMS17, National Bureau of Standards, 1939.

11. DAVIS, A. H., and C. J. MORREAU: "The Reduction of Noise in Buildings," Building Research, Special Report 26, Department of Scientific and Industrial Research, London, 1939.

12. CLOSE, PAUL DUNHAM: "Building Insulation," American Technical Society, 1942.

13. ROWLEY, FRANK B., and RICHARD C. JORDAN: "Economics of Insulation," Bulletin No. 23, Engineering Experiment Station, University of Minnesota, 1945.

CHAPTER XIII

DOORS AND DOOR FRAMES

ARTICLE 78. DEFINITIONS AND GENERAL DISCUSSION

Parts of Doors and Door Frames. The parts of a door are indicated in Fig. 218. The horizontal members are called the *rails*, the vertical members the *stiles*, and the areas included between the rails and the stiles are known as *panels.* The stiles of a door which is hung on one side and has a lock on the other are called the *hanging stile* or *hinge stile* and the *lock stile.* Intermediate stiles are called *muntins.* The rails at the top and bottom of a door are called the *top rail* and the *bottom rail.* The intermediate rail on a door having three rails is called the *lock rail* but if there are two or more intermediate rails they are called *cross rails.* A sash called a *transom* may be placed over a door. The member between the door and the transom is the *transom bar.* The vertical crack between doors set side by side in the same opening may be covered by an *astragal.* These designations apply to most types of doors but not to all. There are many types of doors in use but only the more common types will be considered here. Doors of standard or stock types may be used or special doors may be made to suit individual requirements.

The *frame* which surrounds the door and holds it in position, is illustrated in Fig. 218. It consists of the side members which are called the *jambs,* the top member called the *head,* and the *casings.* Outside door frames are provided with *sills* and with *thresholds.* The threshold enables a door to be cut short enough to clear floor coverings on the inside and still not leave a large crack under the door. Thresholds are sometimes used under inside doors, particularly where the flooring material changes at the door.

Devices are available which close the space under a bedroom door, when the door is closed, and recede into a niche in the bottom edge of the door as soon as it starts to open. Their function is to keep the cold air in a bedroom from entering the rest of the house at night when bedroom windows are open. They are sometimes called *trigger bottoms.* Thresholds also serve this function but they are usually considered objectionable for interior use. These devices are effective in reducing

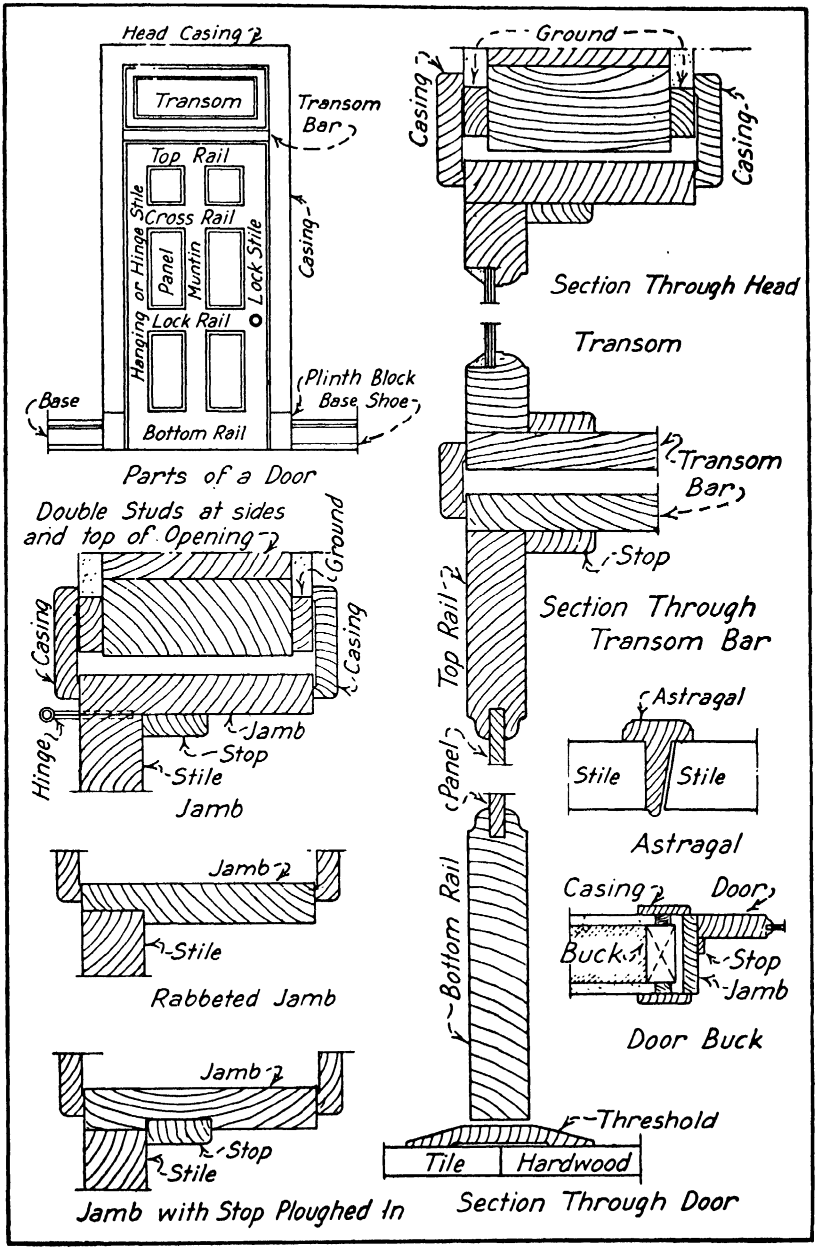


FIG. 218. Parts and Details of a Framed Wood Door

sound transmission. *Stops* are provided for the door to close against and to cover the crack between the door and frame, or the frame is *rebated* or *rabbeted* as shown. The depression cut in the frame to receive the door is called a *rebate* or *rabbet.* An excellent form of stop is the *plowed-in* stop which is set in a groove provided in the jamb as shown. A stop attached to the face of a jamb is said to be *planted.*

Door frames may be set in masonry walls at the time the walls are constructed, in which case they are anchored to the walls by metal anchors which are fastened to the frames and built into the walls. Wood blocks may be built into masonry walls to form an anchorage for frames which are set after the walls are built. Openings to receive door frames are provided in walls and partitions with wood studs by doubling the members forming the jambs and the head. For wide openings, the head should be trussed as shown in Fig. 103*d.* Masonry partitions are provided with *door bucks*, which are rough frames as shown in Fig. 218 set at the time the partitions are built and anchored to the masonry by metal anchors. These bucks are constructed of wood for wood frames and doors and of steel channels or pressed steel for hollow metal doors. The openings provided are larger than the outside dimension of the frames to permit the frames to be plumbed.

Operation of Doors. Doors are usually arranged to open by swinging about a vertical axis or by sliding horizontally but in some cases they may swing about a horizontal axis or slide vertically. These axes are provided by means of *hinges* or *butts* fastened to the door and the door frame. Horizontal sliding doors are suspended from *hangers* containing wheels which operate on tracks placed at the top of the door openings. Vertical sliding doors move between guides provided at the sides and are operated by cables or chains passing over pulleys in much the same way that double-hung windows are operated. They may be either counterweighted or counterbalanced as will be explained later.

The most common type of door is the swinging door shown in Fig. 219*a.* When ordering hardware for doors it is necessary to specify the *hand* and *bevel* of the doors. The hand of a door is determined by the side on which it is hinged. A door is *beveled* when the outer edge of the lock stile is not at right angles to the face of the door. Doors are beveled to keep them from binding on the jamb when opening and shutting. It is evident that the direction of the bevel is determined by the direction in which the door swings when opened. If one is standing on the outside of a door and the butts are at his left, the door is a *left-hand door*, but if they are at his right it is a *right-hand door.* If, in opening the door, it swings away from him, it requires what is called a *regular bevel* but if it swings towards him it requires a *reverse bevel.*

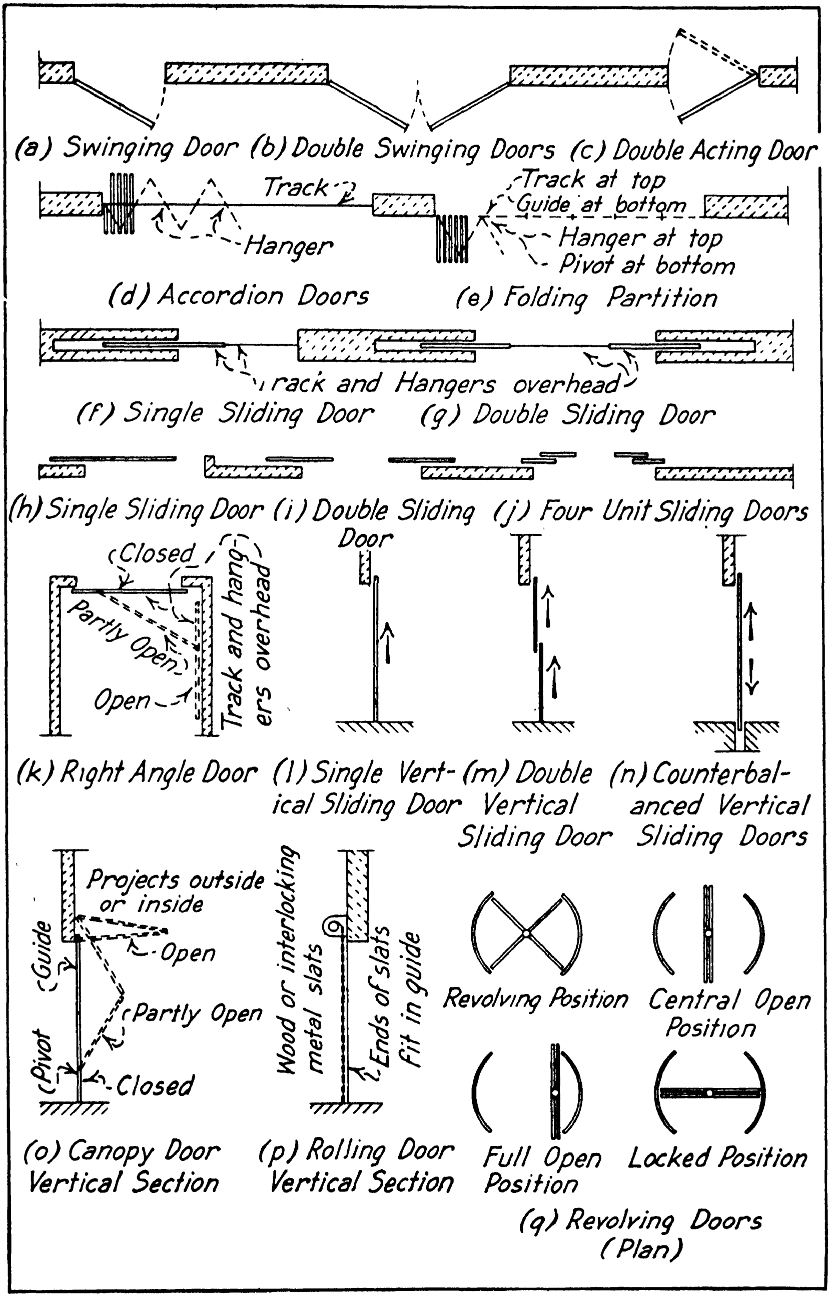


FIG. 219. Operation of Doors

In Fig. 219*a*, if the outside of the door is the side toward the lower edge of the page the door would be designated as left-hand, reverse bevel. The corridor side of interior doors is taken as the outside, as is the room side of closet doors. Many states require that all doors to buildings and rooms where many people congregate swing outward to avoid the possibility of the doors being blocked shut by crowds pushing against them in attempting to get out. Such doors are not permitted to have dead locks which require a key to open from the inside but should have locks operated by knobs or thumb turns from the inside or in the case of schools, theaters, auditoriums, etc., *panic bolts*, which release the lock when a crowd pushes against a door, should be used.

Two doors hinged at opposite sides of an opening, as shown in Fig. 219*b*, are referred to as *double doors*. Such doors are extensively used at the entrances of buildings and of large rooms and even in the small rooms of residences to give a more spacious effect than would be secured with single doors.

The *double-acting door*, shown in Fig. 219*c*, is provided with special hinges which keep the door closed when it is not held open. The door can easily be pushed open in either direction and is convenient for use between a kitchen and dining room where those using the door may be carrying trays, etc.

The folding doors shown in Fig. 219*d* and *e* are used as folding partitions so that two rooms may be used together as a single room or separately. They may be made for very wide openings. Two or three doors hinged together, as shown in Fig. 219*e*, are sometimes used for garages but are unsatisfactory.

The sliding doors shown in Fig. 219*f* and *g* were quite extensively used in residences at one time but swinging doors or *cased openings* without doors have largely taken their place. They slide into pockets provided in the partitions so are out of sight when not in use. The partitions must be about 12 in. thick to provide the pockets.

Doors sliding on one side of a wall or partition, as shown in Fig. 219*h* and *i*, are extensively used for fire doors which nominally stand open but which are released by a *fusible link* in case of fire. They may be made self-closing by sloping the tracks from which they are suspended or by properly arranged weights and pulleys.

Sliding doors, as shown in Fig. 219*i* and *j*, are commonly used for elevator doors. They are so arranged that they will all open when one is pulled back. The inner doors in Fig. 219*j* are arranged to move faster than the other two so that they will all be completely open at the same time. Two doors opening to the same side are more extensively used than the four-door unit shown.

The right-angle door shown in Fig. 219*k* is used to a limited extent on garages. The doors are suspended from an overhead track.

The vertical sliding doors in Fig. 219*l* and *m* are counterweighted and may be operated electrically. They are pulled up by cables or chains at each side of the opening that operate over pulleys in the same manner as for double-hung window sash. Such doors are used for large openings in industrial buildings, particularly for freight elevator doors.

Where conditions permit their use, the counterbalanced vertical sliding doors shown in Fig. 219*n* are convenient. They are extensively used for freight elevator doors and can be easily operated by hand. When one moves up, the other moves down an equal distance.

The canopy door shown in Fig. 219*o* is used for large openings in industrial buildings. The door is counterweighted and may be electrically operated. If desired, it may open outward to form a canopy over the opening.

The rolling door shown in Fig. 219*p* operates in the same manner as a window shade. The roller on which the door rolls is operated by hand or electrically or by a spring which counterbalances the weight of the door. The door is made flexible by using wood slats or interlocking slats of sheet steel. The ends of the slats are held behind guides at the sides of the doors. Wood rolling doors are used to form movable partitions in the same manner as accordion doors and folding partitions shown in Fig. 219*d* and *e*. Steel rolling doors are extensively used for large exterior doors of industrial buildings and for fire shutters which will close automatically in case of fire.

The revolving door shown in Fig. 219*q* is extensively used at the entrances of public buildings, banks, stores, etc. It does not permit much cold air to come in from outside when it is in use. During mild or warm weather when it is not in use the revolving part may be moved out of the way as shown. The door may be locked when desired. Revolving doors are not included when figuring the exits required by building codes. In case of fire, the number of people they would accommodate in a short period of time is relatively small.

Two forms of garage doors which move vertically to open are illustrated in Fig. 220. The door in Fig. 220*a* consists of four leaves which are hinged together as shown. Wheels in the sides of the doors move in guides so that the door takes the position shown in the figure when it is open. A coiled spring balances the weight of the door so that it is easily operated. The product of one manufacturer is called the *Overhead door.* The door shown in Fig. 220*b* consists of a single leaf which is pivoted on each side as shown. It is opened by lifting vertically and rotating around the pivots. A spring is so arranged to assist

in opening the door and to hold the door open. This door requires a wall or other support close to each side of the opening to which the pivots can be attached.

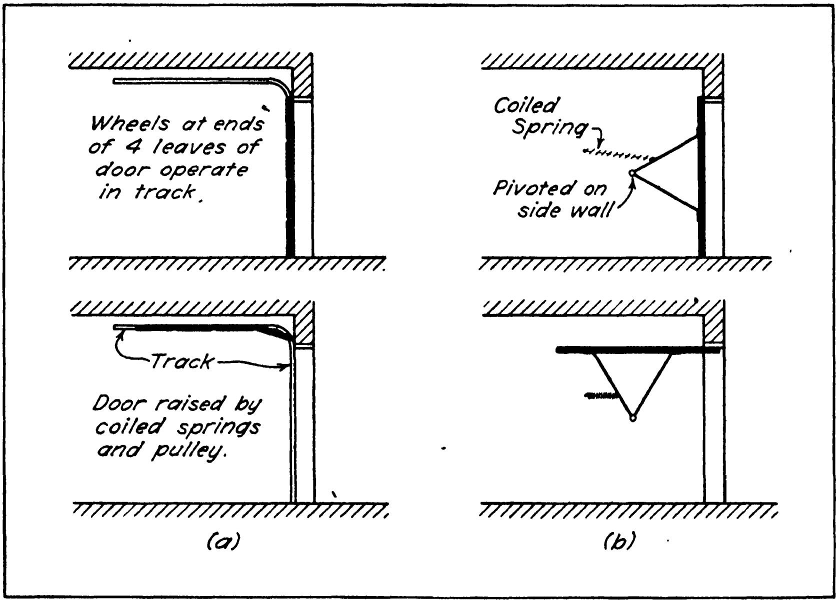


FIG. 220. Vertical-Opening Garage Doors

Code Requirements. Building codes contain requirements concerning doors to insure the safety of the occupants of buildings. The following clauses taken from the Building Code of the National Board of Fire Underwriters[1] may be considered as typical.

1. *Width.* No exit doorway shall have a clear width of less than thirty-six inches. The aggregate clear width of doorways serving as exits for more than forty persons shall be not less than at the rate of twenty-two inches for every one hundred persons to be accommodated.

2. *Hanging of Doors.*

a. The doors of required doorways shall be so hung and arranged that when opened they shall not in any way diminish or obstruct the required width of passageway, hallway, stair, or other means of exit.

b. Except in residence-buildings doorways serving as required exits to a street or to a court or open space communicating with a street, shall have the doors, including the doors of vestibules, so hung as to swing outwards when opening; but this requirement shall not be construed to prohibit the use of doors swinging both inwards and outwards, nor of sliding doors in stables,

garages, or shipping and receiving rooms of business-buildings and storage-buildings.

c. Exit doors leading from rooms occupied by fifteen or more persons, shall be hung to swing in the direction of exit travel.

d. No exit door shall open immediately on a flight of stairs, but a landing the length and width of which are not less than the width of such door, shall be provided between such door and such stairs. No riser shall be located within one foot of an exit door.

Door Fastening. Fastenings on required exit doors shall be such that the door may be readily opened from the inside without the use of keys.

Building codes contain clauses requiring fire doors in exterior walls which are exposed to fire hazards due to the nearness or to the non-fireproof construction of adjacent buildings. Fire doors are also required on the inside of buildings to check the spread of fires. Such clauses apply only to buildings within the fire limits. Fire doors must be so constructed as to resist a fire for one hour under standardized conditions. Various types of metal doors and metal-clad doors will give the required fire protection if properly constructed.

Screen doors are commonly provided at entrances, in addition to the regular doors, to keep insects from entering. They are removed during the winter months and often replaced by *storm doors* to reduce heat losses. Air infiltration is also reduced by *weatherstripping* of various types.

ARTICLE 79. WOOD DOORS

Material. Wood doors may be made of solid softwood such as white pine, cypress, redwood, and fir or they may be made of a hardwood *veneer* such as birch, oak, ash, gum, walnut, and mahogany with a kiln-dried core of some softwood such as white pine.

Veneers are thin sheets of wood. They are made by three processes: the sawing process, the slicing process, and the rotary-cut process. In the *sawing process* the thin sheets of wood are cut from large blocks of wood by a circular saw. This process is wasteful because of the wood consumed in the saw-kerf but it produces the best grade of veneer because it injures the wood less than the other processes. In the *slicing process* the thin sheets are sliced off of the large blocks with a cutting knife. The wood is softened by steaming to make the cutting without splitting possible. In the *rotary-cut process* a log which has been softened by steaming or boiling is placed in a lathe and revolved against a wide stationary blade which gradually moves towards the center of the log and cuts off a continuous slice. The entire log can not be cut up in this manner but a core which must be discarded, so far as this use is concerned, remains.

The thickness of the veneer varies from $\frac{1}{16}$ to $\frac{1}{4}$ in., the thicker veneers being used on the stiles and rails of exterior doors. The veneers on panels are sometimes as thin as $\frac{1}{28}$ of an inch. The veneer is fastened to the core with waterproof glue and is subjected to pressure while the glue is drying. Veneered doors should not be used on the exterior of buildings unless they are protected from the weather. Doors may be obtained with solid stiles and rails, and veneered panels.

Types. Several types of doors are illustrated in Fig. 221.

The *ledged and braced door* shown in Fig. 221*a* is used only on cheap construction and may be made by the carpenters on the job. Its use is ordinarily confined to such buildings as private garages and stables but it is sometimes used in high-class construction where quaintness is desired. The horizontal members are called *ledges,* and the diagonal member is called the *brace.* The brace prevents sagging. Three ledges and two braces are also used. The braces may be omitted if the ledges are securely screwed to the vertical boards. Doors may be constructed of vertical pieces 2 in. or more in thickness held together by horizontal bolts running from one edge of the door to the other and concealed in the thickness of the door. If the wood is well seasoned and the bolts are tight such doors may be very substantial. The heads of the bolts and the nuts are recessed in the edges of the door a sufficient depth so that they may be concealed by wood plugs.

The most common types of doors are *framed doors.* They consist of stiles, rails, and muntins, which are framed together, the enclosed areas being filled with panels. In some of these, glass panels are used instead of solid panels or a mirror may be placed on one side backed up with a solid panel on the other. Doors may have panels provided with slats or *louvers* for ventilating rooms. Doors in which the area included between the outer stiles and rails is divided by muntins supporting lights of glass are called *French doors.* Doors which are divided horizontally so that the upper part may be operated separately or the two parts may operate as a unit are called *Dutch doors.* Doors with plane faces are called *flush doors.* They are always of the veneered type. Flush doors may be obtained with inlaid borders or other inlaid designs. Flush doors are extensively used in hospitals for there is no place on them for dust to collect and they are easily cleaned. For this reason they are often called *sanitary doors.* Many types of doors not mentioned here are readily available, or doors may be built to special design.

Construction. Several types of construction used on solid and veneered doors are illustrated in Fig. 221*b*. The common thicknesses for standard doors are $1\frac{3}{8}$ in. and $1\frac{3}{4}$ in., the greater thickness being used

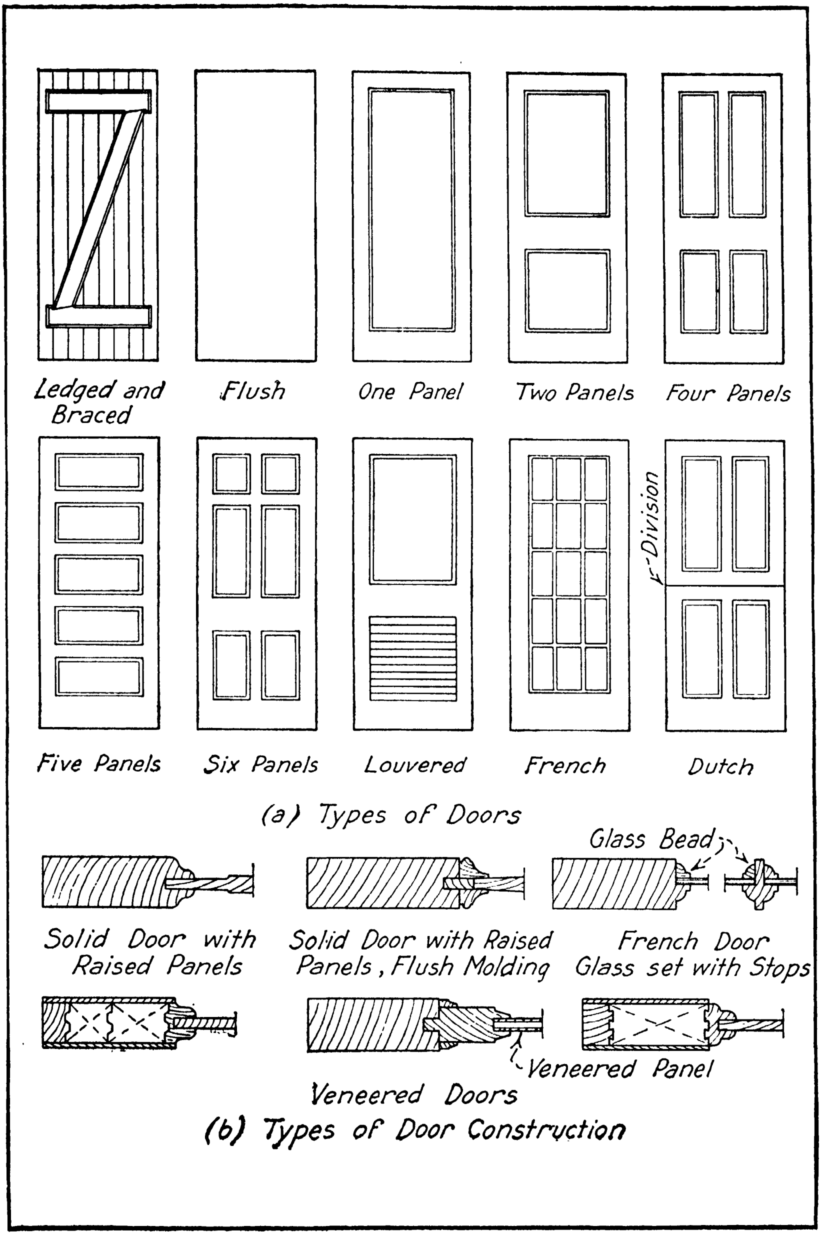


FIG. 221: Types and Construction of Wood Doors

for the larger doors and for exterior doors. The joints between stiles and rails may be of mortise-and-tenon construction or dowels may be used. The following suggestions for the preparation of door designs have been made by door manufacturers:

The cores of veneered doors should be kiln-dried softwood.

Veneers for stiles and rails of exterior doors should be not less than $\frac{1}{4}$ in. thick.

One-panel doors should be not less than $1\frac{3}{4}$ in. thick.

Doors over 2 ft. 8 in. wide or 7 ft. high should be not less than $1\frac{3}{4}$ in. thick.

Doors veneered with two kinds of wood should be not less than $1\frac{3}{4}$ in. thick but they should be avoided if possible. For such doors, do not use rabbeted jambs or plowed-in stops.

Flush or sanitary doors should be not less than $1\frac{3}{4}$ in. thick.

The bars or muntins on French or sash doors should be preferably $\frac{1}{2}$ in. thick between glass.

The jambs and heads of door frames are commonly made from $\frac{7}{8}$ in. to $1\frac{3}{4}$ in. in thickness, the thicker material being required for rabbeted frames.

Door Sizes. The standard sizes for stock doors vary with different manufacturers. The smallest door which is used to any extent is 2 ft. 6 in. wide by 6 ft. 6 in. high. This size of door is very common in residences but a 2 ft. 8 in. by 6 ft. 8 in. door is advantageous when moving furniture in and out. Office and schoolroom doors are commonly made 3 ft. by 7 ft. Doors wider than 3 ft. or higher than 7 ft. are not extensively used except as entrance doors or for special uses such as in hospitals where doors from 3 ft. 6 in. to 4 ft. wide are used to provide clearance for hospital beds.

In general, doors may be obtained varying in width from 2 ft., by intervals of 2 in., to the width of 3 ft. and in height from 6 ft. 6 in., by intervals of 2 in., to the height of 7 ft., although doors 2 ft. by 6 ft. are available. All of these sizes may usually be obtained $1\frac{3}{8}$ in. thick, and doors 2 ft. 6 in. or more in width may be obtained $1\frac{3}{4}$ in. thick. Doors thinner than $1\frac{3}{8}$ in. are used only on cupboards or for similar uses and doors thicker than $1\frac{3}{4}$ in. are rarely used except for special entrance doors.

ARTICLE 80. HOLLOW-METAL DOORS AND METAL-COVERED DOORS

Hollow-metal doors are usually made of No. 18 gage furniture steel shaped as shown in Fig. 222*b* to form doors resembling wood doors in appearance. The top and bottom rails are commonly reinforced with

steel channels concealed inside and reinforcement is provided where hinges, locks, door checks, etc., are to be attached. All seams and joints between stiles and rails are welded and so finished that they are invisible. Cork inserts are placed in the stiles and rails to prevent the metallic sound the door would otherwise make when jarred by closing. The panels are lined with asbestos. The stiles and rails of the most fire-resistant types of doors are lined with asbestos. The finish on hollow-metal doors is commonly baked enamel.

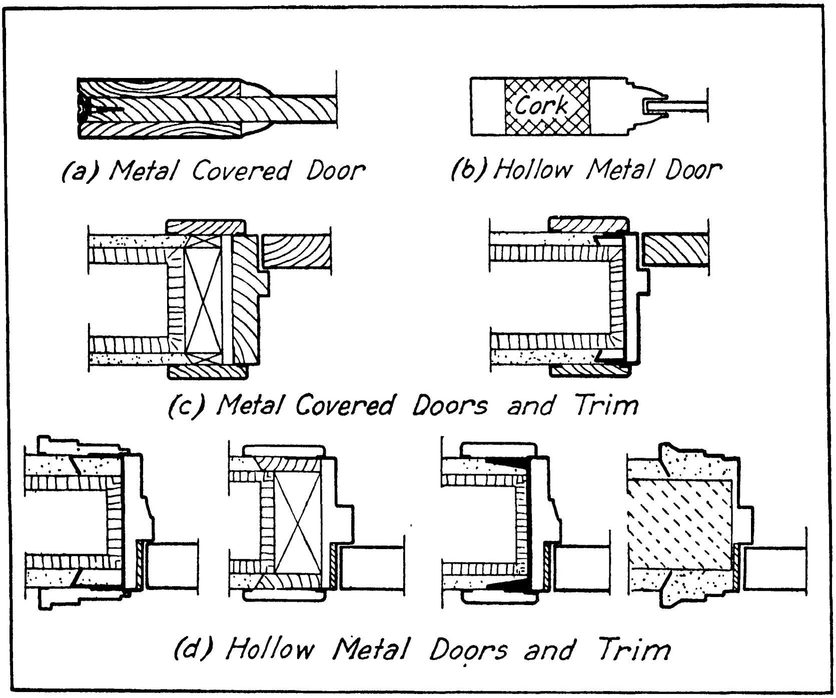


FIG. 222. Metal-Covered and Hollow-Metal Doors and Trim

Hollow-metal doors are provided with pressed steel frames and trim which are fastened to pressed steel bucks, steel channel bucks, or wood bucks, as shown in Fig. 222*d*, or the frame and buck may be combined as shown. Hollow-metal doors are also made of No. 14 gage sheet bronze and of extruded bronze members. Hollow-metal doors may be used in preference to metal-covered doors and wood doors on account of their greater fire-resisting qualities and their freedom from shrinkage and swelling. They are more expensive than metal-covered doors and much more expensive than wood doors. They may be obtained in any desired

style such as panel doors, flush doors, and French doors, as shown in Fig. 221, but each manufacturer has standard types. The sizes correspond approximately to those of wood doors, a common thickness being 1¾ in., but elevator doors are made as thin as 1¼ in., and large doors as thick as 2¼ in.

Metal-covered doors consist of cores of thoroughly dried non-resinous lumber such as white pine covered with a tight-fitting sheet-metal covering of furniture steel, galvanized steel, cold-rolled copper, sheet bronze, or kalamein metal which is steel with a thin coating of lead and tin and is called terne plate, as shown in Fig. 222*a*. The term *kalamein* is commonly applied to any metal-covered wood regardless of the metal used.

Wherever possible, the metal covering is tightly fitted to the core by drawing through dies. Panels are commonly made of asbestos or other fireproof composition board with metal glued on both sides under pressure with waterproof glue. Mortise-and-tenon joints are commonly used between the wood rails and stiles, and the metal joints are locked and soldered so that they are practically invisible and are tight so that moisture cannot penetrate into the door. Metal-covered frames and trim are available for use with metal-covered doors as shown in Fig. 222*c*.

Metal-covered doors are used where their moisture-proof or fire-resistant qualities are desired. They are not as fire-resistant as hollow-metal doors but are less expensive. They are considerably more expensive than wood doors.

The door sizes and styles for hollow metal and metal-covered doors correspond quite closely with those of wooden doors as shown in Fig. 221.

Doors are also made of bronze, aluminum, and nickel silver, or white metal.

ARTICLE 81. TIN-CLAD, SHEET-STEEL, CORRUGATED-STEEL, AND ROLLING DOORS

Fire-resistant doors of various designs are on the market for use where hollow metal doors or metal-covered doors are too expensive and out of keeping with the use to which they are put. They are used in factories, warehouses, garages, etc., where appearance is not a factor. The most common types are the tin-clad door, the steel-plate door, and the corrugated-steel door.

Building codes require that doors in fire walls and other critical locations be so constructed as to provide a specified degree of fire resistance. Such doors are required to be self-closing or to be provided with automatic closers which will operate under the action of heat and cause the doors to close.

Tin-Clad Doors. Tin-clad doors consist of a wood core covered with terne plate. The cores are made of either 2 or 3 layers of 1-in. boards preferably tongued and grooved and not over 8 in. wide. If two layers are used, one is vertical and the other horizontal. If three layers are used, the outer layers are vertical and the inner layer horizontal. The layers are securely fastened together by clinched nails or in some other manner to give smooth surfaces. The covering of terne plate is made up of 14- by 20-in. sheets, preferably with double-lock joints. Solder, if used, must serve only to improve the appearance. The terne plate is held flat against the core by nails.

The three-ply doors are required where the most effective resistance is desired, and the two-ply where only a moderate degree of protection is necessary.

Tin-clad doors are commonly surrounded with heavy angle frames to which they are bolted.

Steel-Plate Doors. Steel-plate doors consist of steel plates fastened to one side of an angle-iron frame or both sides of a channel frame, the frames being braced by intermediate members.

Corrugated-Steel Doors. This type of door is constructed of heavy corrugated-steel sheets supported by a structural steel frame. The better class of doors consist of two thicknesses of corrugated sheets, one being placed with corrugations vertical and the other with corrugations horizontal, with an asbestos lining between the sheets. This lining is from $\frac{1}{8}$ in. to 1 in. in thickness. In some cases the structural steel frame is covered with a $\frac{1}{8}$-in. layer of asbestos. A cheaper and less fire-resistant door is made of one thickness of corrugated steel, with corrugations vertical, riveted to an angle-iron frame, intermediate braces being provided where necessary.

Steel Rolling Doors. This type of door consists of a curtain of interlocking corrugated steel slats which rolls up on a roller or drum in much the same way as a window shade. See Fig. 219*p*. The edges of the curtain operate in vertical guides and the roller is housed in a steel hood. The curtain may be counterbalanced by springs so that it can be easily raised or lowered by hand; it may be operated by an endless chain with sprocket and gear, by a crank, or it may be operated by electric motor. Devices for closing the door automatically, in case of fire, are available.

REFERENCES

1. Building Code, National Board of Fire Underwriters, 5th Ed., Revised Reprint, 1934.
2. "Sweet's Catalog File," F. W. Dodge Corporation.

CHAPTER XIV

WINDOWS

ARTICLE 82. DEFINITIONS AND GENERAL DISCUSSION

Parts of a Window. The parts of windows of various types are indicated in Figs. 223 to 226. The two principal parts are the frame and the sash. The *frame* is the outer part of the window which is solidly fixed to, or built into, the wall and supports the *sash* which carry the glass and which may be fixed in position or may be arranged to open. The frame consists of four principal parts: the two vertical side members called the *jambs,* the horizontal member at the bottom called the *sill,* and the horizontal member at the top called the *head.* There may be one or more sash in a frame arranged in various ways, as described later in this article.

Frames may be subdivided by vertical members called *mullions.* A sash is usually rectangular and consists of two side members called *stiles,* a top member called the *top rail,* and a bottom member called the *bottom rail.* A sash may carry one *light* or *pane* of glass or may be subdivided by means of vertical and horizontal members, called *muntins,* to carry several lights of glass. In *leaded glass windows* the glass is subdivided by lead strips which may be arranged to form rectangles, figures, or patterns. Windows of Gothic buildings are often ornamented by dividing the glass by means of bars of stone forming *tracery.* Wood is commonly substituted for stone to reduce the cost. A sash is held in its frame by means of *stops* which form ridges around the inside of the frame on each side of the sash. Glass is held in position by means of putty or *glass beads.*

If two sash are set one above the other in a frame and so arranged as to slide past each other, the top rail of the lower sash and the bottom rail of the upper sash are arranged to overlap and are called *meeting rails* or *check rails.* If sash are arranged to swing by hinging them to the stile on one side, the stile to which the hinges are fastened is called the *hanging stile.* If such sash are placed in pairs in a frame the stiles which are adjacent in the center of the frame are called *meeting stiles.*

Types of Windows. Windows may be divided into several types depending upon the provision made for operating the sash. If sash do not operate they are called *fixed sash.* See Fig. 223*a.* Sash which are hinged on one side are called *casements.* If they swing outward, as

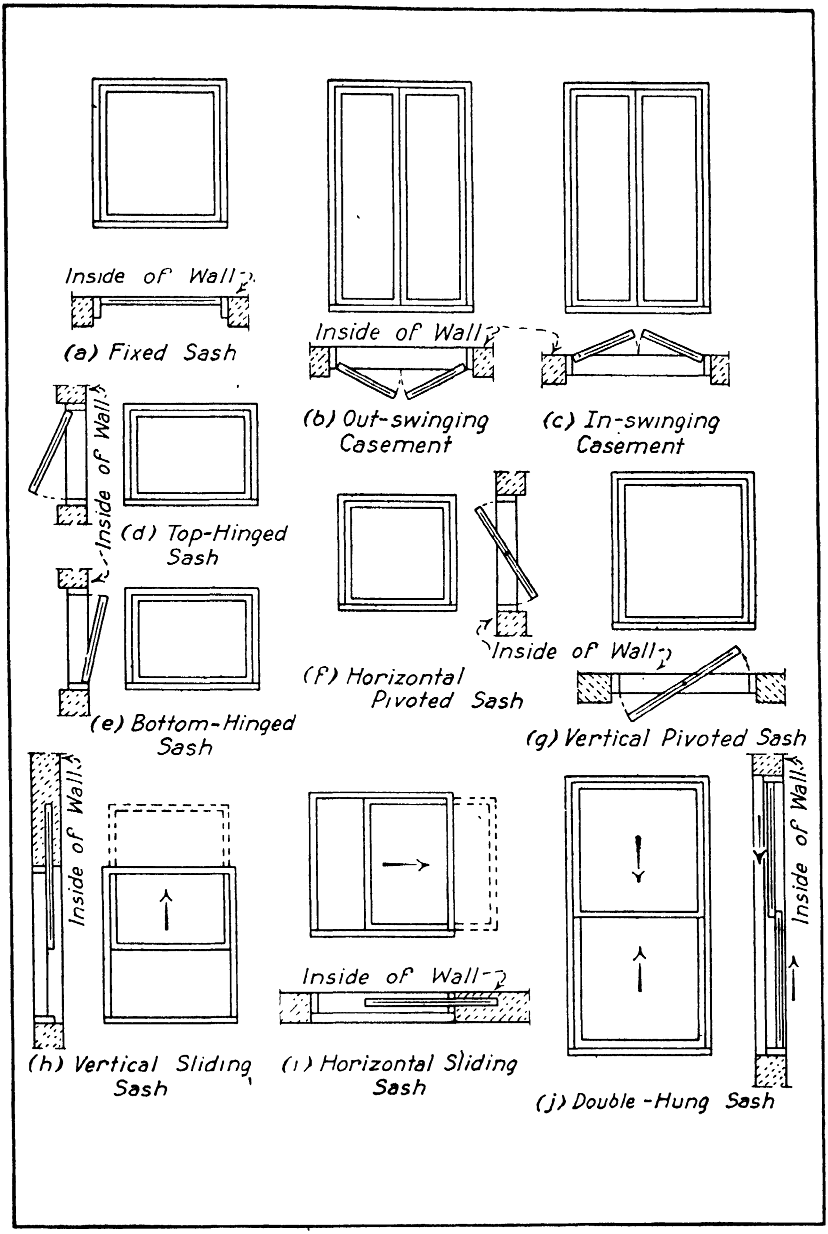


FIG. 223. Operation of Windows

shown in Fig. 223*b,* they are called *out-swinging casements,* and if they swing inward, as shown in Fig. 223*c,* they are called *in-swinging casements.* Sash may be hinged at the top and swing outward or inward, as shown in Fig. 223*d,* or may be hinged at the bottom and swing inward, as shown in Fig. 223*e.* They may be pivoted at the centers of the stiles and rotate about a horizontal axis, as shown in Fig. 223*f,* or they may be pivoted at the center of the top and bottom rails and rotate about a vertical axis, as shown in Fig. 223*g.* A single sash may slide vertically, as shown in Fig. 223*h,* or horizontally, as shown in Fig. 223*i.* If two sash are placed in a frame and are so arranged that they can operate by sliding vertically by each other, as shown in Fig. 223*j,* they are said to be *double-hung.* In order to keep the rainwater which drains down over the upper sash from running in behind the lower sash the upper sash is always set outside of the lower sash. Windows with double-hung sash which are connected together by sash cords or chains passing over pulleys in such a way that one automatically lowers when the other is raised are called *counterbalanced windows,* the weight of one sash balancing the weight of the other. If each sash is balanced independently by weights operating in the *weight box,* the sash are said to be *counterweighted.* Coiled springs may be used instead of counterweights. Other types of sash have been brought on the market by the manufacturers of metal sash. These will be considered later under the heading of metal sash.

The most common type of window is that with double-hung sash with counterweights or sash weights and, excepting factory sash, the next in popularity is the casement. The double-hung window is a satisfactory type of window and one easily made weathertight. The chief objection to double-hung windows is that they permit only half of the window section to be opened for ventilation. Out-swinging casements require the screen to be on the inside. Operators are available which do not require the screen to be opened to operate the sash. The full area of the window may be opened. In-swinging casements must be carefully designed to keep rainwater from leaking in around the lower edge of the sash, they interfere with window drapes and with shades when opened and since they swing into the rooms they may be in the way. For these reasons they are considered by many an unsatisfactory type of sash. However, a properly designed sash will not leak and shades and curtains may be fastened to the sash themselves, thereby partially overcoming the objections to this type of sash. It provides the full area for ventilation. Casement sash are often arranged in pairs, two narrow sash being used instead of one wide sash. Long casement windows reaching nearly to the floor are sometimes called *French windows.*

Materials for Windows. Window sash and frames are made of wood and of metal. The kinds of wood selected for the various parts of a window should be suitable for the service they are to perform. The sash have to withstand severe exposure and hard usage and they must not warp out of shape or shrink. Some of the kinds of wood which have been found to render satisfactory service for sash and other exposed parts are white pine, sugar pine, redwood, cedar, and Douglas fir. The *pulley stiles* over which the sash of double-hung windows slide are subjected to considerable wear, so it is desirable to make these members of hard pine or some hardwood. The parts of a window which are not exposed are made of almost any kind of lumber available at low cost.

Metal windows are divided into three general classes: rolled or solid metal, hollow metal, and metal-covered windows. Metal windows are made of copper-bearing or non-copper-bearing steel, galvanized steel, nickel silver, cold-rolled copper, and bronze. Metal-covered windows consist of a core of non-resinous wood such as white pine over which is tightly fitted a sheet-metal covering of one of the following materials: terne plate, galvanized iron, cold-rolled copper, or sheet bronze.

The leakage of air through windows may be reduced by means of *weatherstripping.*

Size of Windows. The Revised Code of Lighting School Buildings prepared by the Illuminating Engineering Society recommends that rooms be so designed that no work space is distant from the window farther than twice the height of the top of the window from the floor, and states that tests of daylight in well-lighted school buildings indicate that, in general, the window glass area does not fall below 20 per cent of the floor area. As the upper part of the window is more effective in lighting the interior than the lower part, this code recommends that the top of the glass be not more than 12 in. below the ceiling.

The following requirements for window area are given in Ketchum's "Steel Mill Buildings":[1]

Where buildings are lighted by windows having the sills not more than 4 ft. above the floor, the span of the building shall not exceed 2 times the height of the top of the windows where buildings are lighted by windows in one side, or 4 times the height of the top of the windows where buildings are lighted by windows in both sides. Where the span of the building is greater than is permitted by the preceding requirement, the necessary illumination shall be provided either by prism glass in side walls or by skylights. Skylights shall have such an area and shall be so arranged that light coming through the skylight making an angle of not more than 45° with the vertical shall cover the entire

horizontal area at a distance of 6 ft. above the floor; or the light may be diffused by means of ribbed glass or prisms or by reflection from the ceiling to obtain equally satisfactory illumination. In saw-tooth roofs the inner surface of the roof shall be light-colored or shall be painted with a paint that will reflect the light and make the illumination uniform and effective.

Building eodes commonly require rooms for human occupancy to have a window or skylight area of from one-eighth to one-tenth the floor area, at least one-half of which is arranged to open for ventilation. Properly designed artificial lighting and mechanical ventilation may be used instead of windows and skylights. This practice is increasing.

Shutters and Storm Sash. Windows may be protected by shutters hinged to the sides of the openings on the outside. These may be of wood, but if they are to protect a building from outside fires they are of steel. Building codes require steel shutters for severe exposures within the fire limits. Wood shutters are often used for decorative purposes and always left open. In some cases they are false shutters with no provision for closing. They are sometimes provided with louvers so as to obscure the view from the outside or shut out the light when closed but still permit ventilation. Inside shutters were used for this purpose many years ago but have gone out of use.

During the winter months screens are commonly replaced with storm sash in the colder climates to reduce the heat losses through windows.

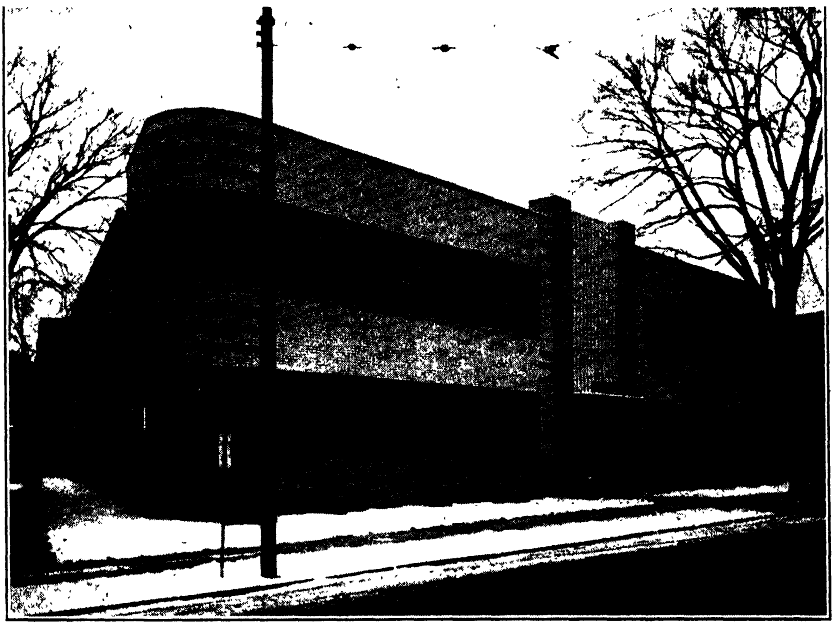
Fire Windows. Windows which are likely to be exposed to exterior fires are commonly required to be of fire-resistant construction if located within the fire limit districts. Such windows are called *fire windows* and are required to withstand a fire for a period of one hour under standardized conditions. The size of a single pane or light is limited to 720 sq. in. with a vertical dimension not exceeding 54 in. and a horizontal dimension not exceeding 48 in. The glass used in fire windows is wire glass at least $\frac{1}{4}$ in. thick containing a layer of wire fabric reinforcement having a mesh not larger than $\frac{7}{8}$ in. and a size of wire not smaller than No. 24 B & S Gage. Hollow metal windows and windows with solid steel sections are satisfactory for fire windows when properly constructed for that purpose.

The National Board of Fire Underwriters maintains the Underwriters' Laboratories for the purpose of testing the fire-resisting properties of building materials and appliances.

Glass-Block Masonry. Glass blocks, as described in Art. 29, are being used extensively to replace windows in providing natural illumination. Ventilation and other factors in air conditioning are then provided artificially. The blocks may be placed as panels in other masonry

corresponding to window openings or they may be placed in continuous bands, with or without windows, as illustrated in Fig. 224.

Windowless Buildings. There has been a tendency to construct some types of buildings such as factories and stores without windows and to depend entirely on artificial illumination and ventilation so that the illumination and air conditioning can be accurately controlled. Such buildings are sometimes called *blackout buildings* because no lighted areas are visible outside at night.



Owens-Illinois Glass Co.

Fig. 224. Building with Glass-Block Masonry

ARTICLE 83. WOOD WINDOWS

The common types of wood windows are the double-hung and the casement. Wood frames and sash are constructed in a great variety of ways; so the details given in this article only illustrate the general type of construction.

The thickness of sash for all types of windows is commonly $1\frac{3}{8}$ in. or $1\frac{3}{4}$ in. The thicker sash are somewhat more expensive but should always be used in the better classes of buildings on account of their greater strength and rigidity.

A double-hung counterweighted window designed to be placed in a masonry wall is illustrated in Fig. 225. It consists of the following prin-

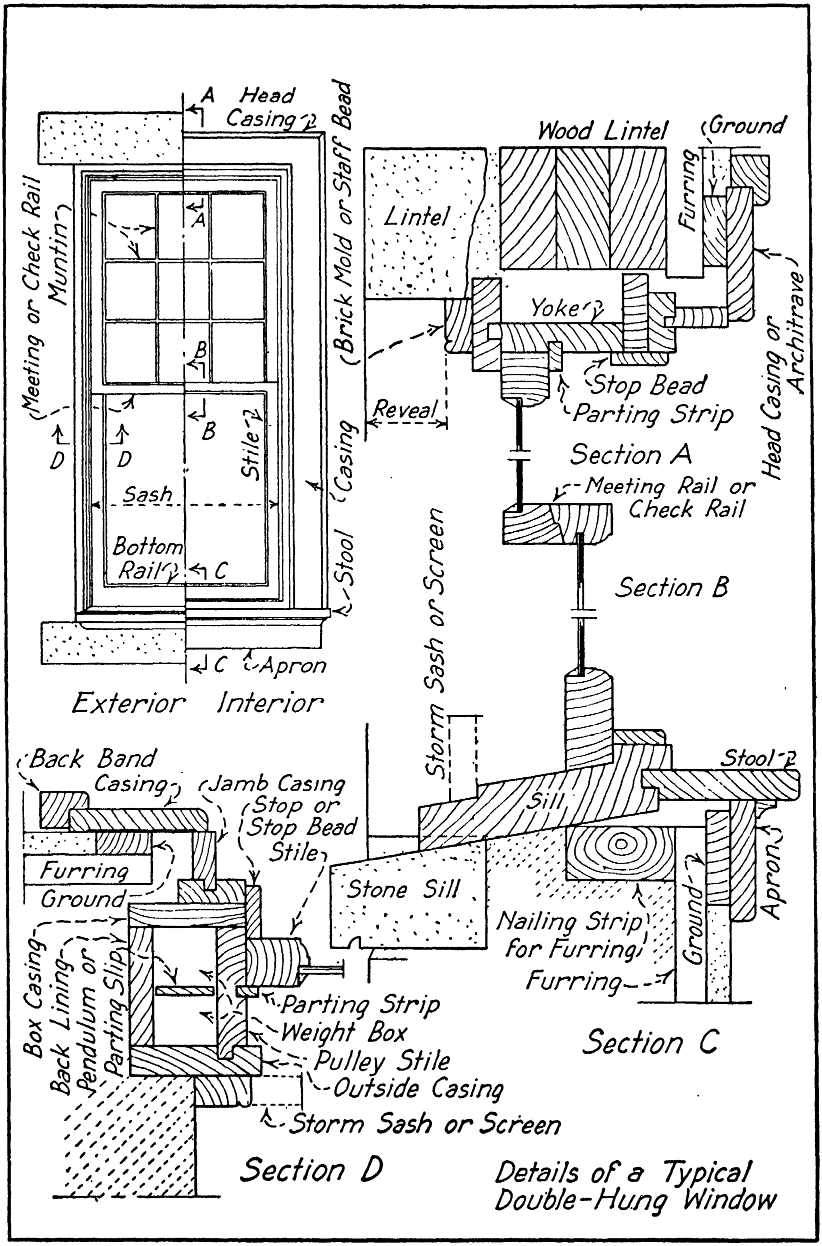


FIG. 225. Details of Wood Double-Hung Window

cipal parts: the frame, the sash, and the interior trim. The principal parts of the frame, i.e., the head, jambs, and sill, and the parts of a sash are defined in Art. 82. The following additional parts of a window are shown in Fig. 225:

Weight box. The box provided to house the weights.

Pulley stile. The part of the weight box next to the sash and against which the sash slide.

Back lining. The part of the weight box next to the masonry.

Box casing. The side of the weighted box.

Parting strip. The guide between the two sash.

Stop or stop bead. The outer and inner guides for sash.

Pendulum. A thin partition of wood or sheet metal in the weight box to keep the weights from interfering with each other. This is fastened at the top only, so that it can be pushed aside to reach both sides of the weight box for repairs, through the pocket. This is also called a *parting strip.*

Pocket. The removable section of the pulley stile to give access to the interior weight box.

Yoke. The top member of the frame.

Sill. The bottom member of the frame.

Stool. The sill of interior finish.

Apron. The part of finish below stool.

Casing. The interior trim at sides of opening.

Head casing. The interior trim at top of opening.

Grounds. The strips under interior trim arranged to serve as guides to fix thickness of plaster and as nailing strips for interior finish.

Brick mold. The mold in outside corner between frame and brickwork.

Staff bead. The general term for brick mold to apply to other materials.

Reveal. The exposed masonry on jamb between frame and outside face of wall.

Jamb casing. The interior trim on jambs of opening where frame is so set as to give a reveal on inside of opening.

Pulley. A pulley is set in pulley stile to receive the sash cord which connects the sash and the counterweight or sash weight.

In order to secure narrow interior trim on window openings, narrow rectangular sash weights may be used instead of common cylindrical weights which are circular in cross-sections. This reduces the required width of the weight box. The same result is accomplished by one type of sash which substitutes coiled springs for counterweights. These are placed in recesses in the exposed faces of the stiles which would otherwise be the pulley stiles. The weight box is eliminated entirely. The springs are on both sides of the sash and the lower ends are attached at the bottoms of the upper and lower sash and the upper ends at the top of each stile. They are so adjusted that the sash are held in any desired position by friction of the weatherstripping.

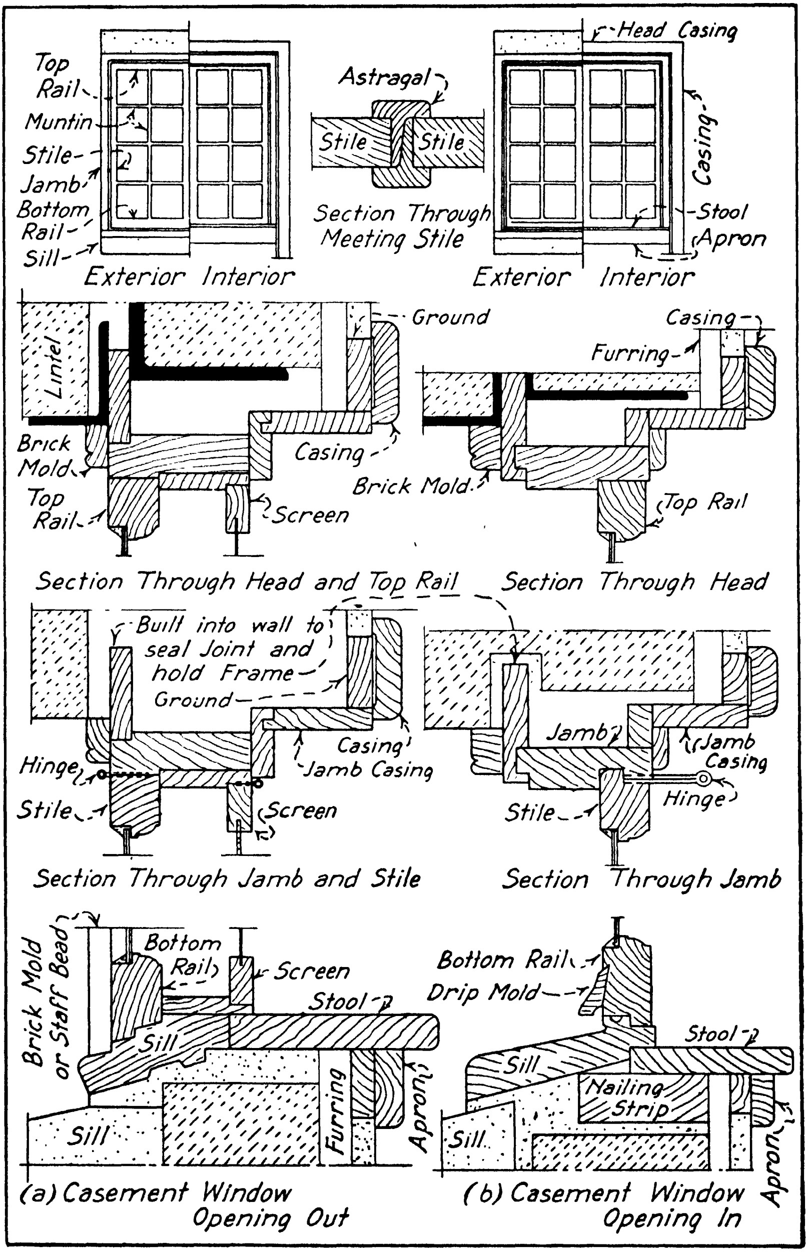


FIG. 226. Details of Wood Casement Windows

An out-swinging casement window for a masonry wall is illustrated in Fig. 226*a*, and an in-swinging casement window in Fig. 226*b*. They consist of the following principal parts: frame, sash, and trim. Casement windows commonly have two sash. The width of a sash should not exceed 2 ft. 6 in., and its height 5 ft., smaller dimensions than this being desirable. The parts of casement windows correspond in general to those of double-hung windows and are shown in Figs. 226*a* and *b*.

ARTICLE 84. SOLID-SECTION METAL WINDOWS

Solid-section steel windows are constructed of light rolled-steel sections as shown in Fig. 227. They are divided into the following classes according to the provision made for opening: pivoted windows, projected windows, horizontal-rolling windows, counterbalanced windows, and double-hung windows. In general, the glass sizes are 12 by 18 in. and 14 by 20 in.

In *pivoted windows,* 4, 6, or 8 lights are arranged in a unit to form a ventilator which may be opened. In the *horizontally pivoted windows,* the ventilator is pivoted on a horizontal axis near its center, as shown in Fig. 227*a*. This type of ventilator is indicated by dotted diagonal lines drawn across the ventilator, as shown in Figs. 227*a* and 228*a,* the intersection being in the center. In the *top-pivoted windows,* the ventilator is pivoted on a horizontal axis near its top. This type of ventilator is indicated by dotted lines meeting at a point near the top of the ventilator, as shown in Fig. 228*b*. The ventilator of *vertically pivoted windows* is pivoted on a vertical axis in the center of the ventilator. It is indicated by dotted lines drawn across the corners of the ventilator as shown in Fig. 228*c*. In the *side-hinged* or *casement window,* the ventilating unit is hinged at the side, as shown in Fig. 228*d*. This type of window is indicated by two dotted lines drawn across the corners, as shown in the figure, and meeting on the side on which the ventilator is hinged.

In *projected windows,* the ventilator is held in position by an arm on each side of the unit, one end of each arm being hinged to the ventilator and the other to the fixed part of the window, as shown in Fig. 227*b*. If the ventilator is to project out, the top of the ventilator moves down as the bottom swings out; but, if the ventilator is to project in, the bottom of the ventilator moves up as the top swings in. The method of indicating the projected-out and projected-in ventilators is shown in Fig. 228*e*, the dotted lines intersecting at the side which moves up and down and about which rotation takes place. Projected windows are of two general types: commercial and architectural. The *commercial* type

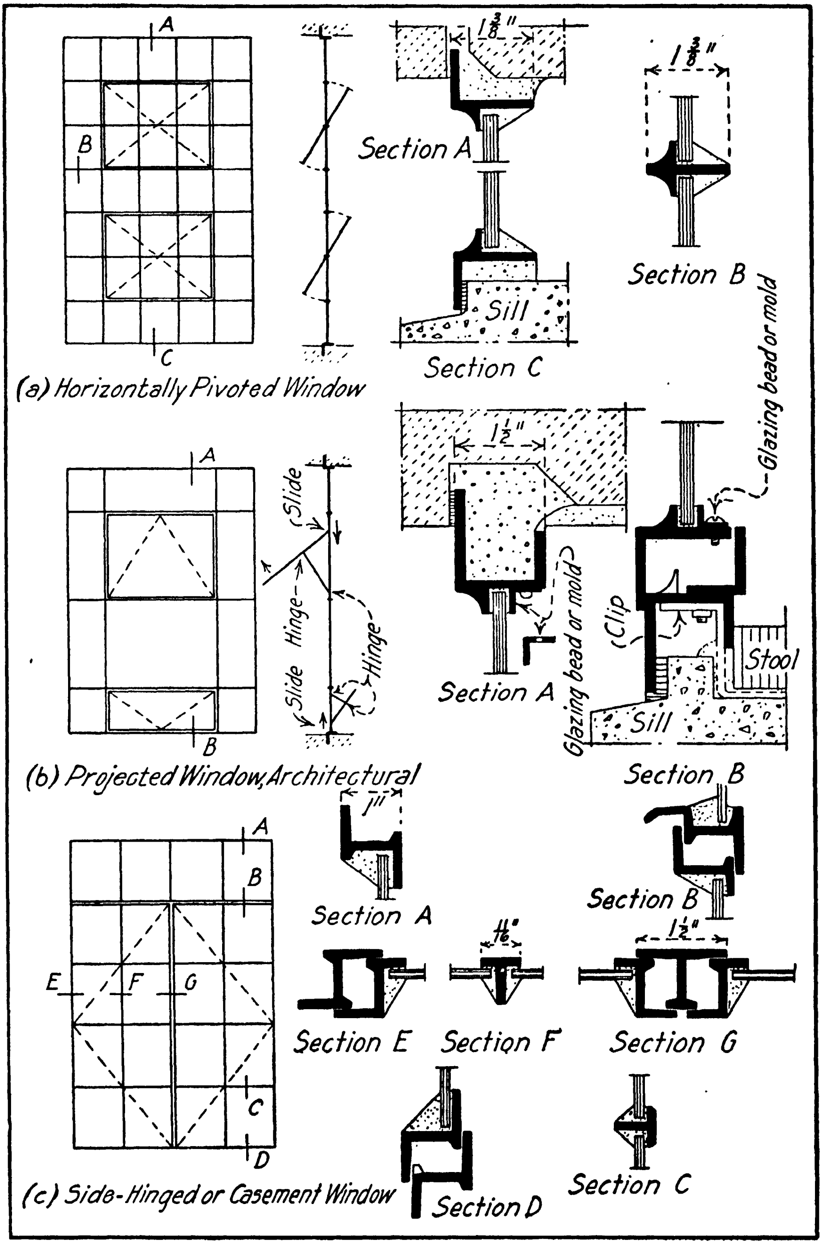


FIG. 227. Solid-Section Steel Windows

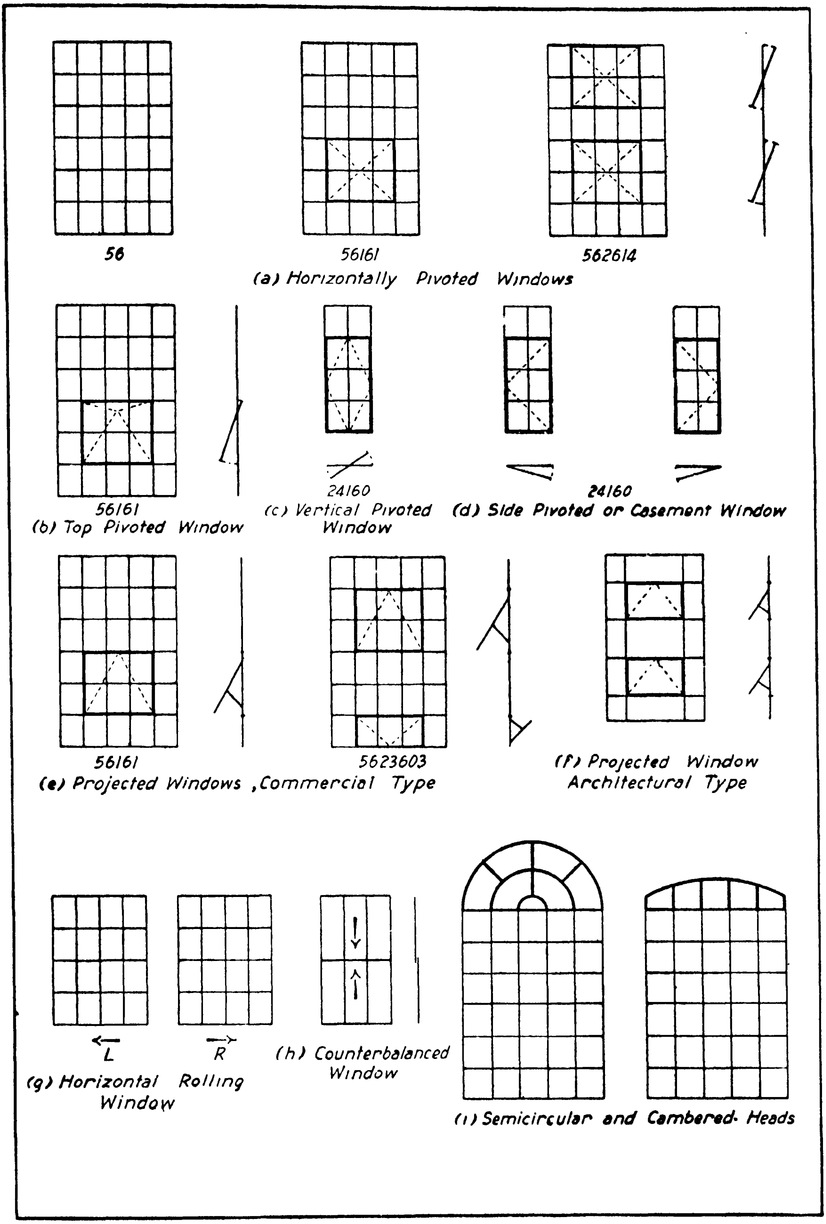


FIG. 228. Types of Solid-Section Steel Windows

is similar in appearance to pivoted windows. It is divided into small lights 12 by 18 in. or 14 by 20 in. in size. The *architectural* type, as shown in Fig. 227*b* and 228*f*, has a heavy outside frame which gives it a better appearance than the commercial type, and the glass in the ventilator is in one sheet.

Horizontal-rolling windows are indicated as shown in Fig. 228*g*, the *L* or *R* indicating whether they roll to the left or right in opening.

Counterbalanced windows are indicated as shown in Fig. 228*h*.

Curved heads are available for use with most of the types of windows which have been described. They are either semicircular or cambered as shown in Fig. 228*i*. In general, they are bolted directly to the windows below, but some of the wider semicircular heads require horizontal mullions.

Windows may be arranged side by side to form groups of any width by using vertical mullions between them. Standard rolled-steel mullions are available.

Screens are on the market for all types of ventilators.

Some of the methods used in fastening steel windows in masonry are indicated in Fig. 227. They may be built in as the masonry is laid, but in general it is considered better practice to place them after the walls are completed, the necessary grooves and chases being left to receive them. If this practice is followed, they are fastened in the grooves with cement grout. Steel windows may be bolted to structural-steel sections where this method of fastening is convenient.

Steel sash are often provided with *wood surrounds* which consist of moldings surrounding the frame. They may be set in wood frames especially when used in connection with frame or masonry veneer construction. These practices increase the width of the members surrounding the frame and probably improve its appearance; but, by using wood where not necessary, in connection with metal windows, one of the advantages of such windows is lost because wood is subject to decay. However, the advantages may offset the disadvantages for such uses.

Pivoted windows, commercial projected windows, and horizontal-rolling windows are made up of several lights of equal size. The method of designating the size of window is of interest. The window number is made up as follows: the first digit is the number of lights wide, and the second the number of lights high. For instance, the first window in Fig. 228*a* is 5 lights wide and 6 lights high, so is designated 56. The third digit indicates the number of ventilators; the fourth, the number of lights in the ventilator if all the ventilators are of the same size; the fifth, the number of rows of lights between the lower ventilator and the bottom of the window; and the sixth, the number of rows of

lights between the upper ventilator and the bottom of the window. For instance, the second window in Fig. 228*a* is 5 lights wide, 6 lights high, has 1 ventilator with 6 lights, placed 1 light from the bottom, and so its number is 56161. The third window in Fig. 228*a* has two ventilators of equal size. It is 5 lights wide, 6 lights high, has 2 ventilators, each with 6 lights, the lower one is placed 1 light from the bottom, and the upper one 4 lights from the bottom, so its number is 562614. The second window in Fig. 228*e* has two ventilators of unequal size. It is 5 lights wide, 6 lights high, has 2 ventilators, and one with 3 lights, one with 6 lights, the lower one being 0 lights from the bottom, and the upper one 3 lights from the bottom; so its number is 5623603. In these types of windows there are never more than two ventilators. The meaning of the dotted lines across the ventilators has been explained elsewhere.

The most common type of steel window for industrial buildings is the horizontally pivoted window shown in Fig. 227*a*. Top-pivoted and vertically pivoted windows are used to a limited extent on industrial buildings. The use of projected windows of the commercial type in industrial buildings is increasing and the architectural type is being rather extensively used in the better class of buildings such as schools and office buildings. Horizontal-rolling windows are rarely used, but counterbalanced windows are quite common in the better class of industrial buildings.

Side-hinged or casement steel windows with solid sections are used for residences and apartment houses. They are usually out-swinging. but in-swinging casements are available.

Double-hung counterweighted or spring-balanced windows with solid-steel sections are used in office buildings, schools, hotels, and other buildings of this class.

Continuous windows are very wide windows which are usually top-pivoted and are mechanically operated. They are used in monitors, in saw-tooth roofs and on the side walls of industrial buildings.

Solid-section metal windows are usually made of copper-bearing steel, but bronze is sometimes used for casement and double-hung windows in high-class buildings. Galvanized-steel windows are quite extensively used.

A standard nomenclature for solid-section steel windows is given in Simplified Practice Recommendation 72 of the United States Department of Commerce. In this nomenclature, the term *window* has been substituted for the term sash; the terms side-wall sash, rolled-steel sash, solid-steel sash, pivoted factory sash, standard steel sash, and solid-steel industrial sash have been replaced by the single term, *pivoted windows;*

type B, reversible sash, projected sash industrial type B, and industrial projected sash are classed as *projected windows, commercial;* type A reversible sash, projected sash architectural type A, and architectural projected sash are classed as *projected windows, architectural;* and continuous sash and monitor sash are called *continuous windows.* This nomenclature has been adopted by many manufacturers.

ARTICLE 85. METAL-COVERED AND HOLLOW-METAL WINDOWS

The common types of metal-covered windows are the double-hung and the casement. The various parts of metal-covered windows are made of a non-resinous wood, such as white pine or cypress, with a tight-fitting sheet-metal covering of furniture steel, galvanized steel, cold-rolled copper, sheet bronze or kalamein metal, which is a trade name for steel with a thin coating of lead and tin and is called *terne plate.* However, the term *kalamein* is commonly applied to metal-covered wood regardless of the metal used. For example, wood covered with copper is frequently called copper kalamein.

Where it is possible to do so, the metal covering is drawn on the wood core through steel dies. The wood cores are accurately shaped and securely framed at all joints. In addition to the fire-resisting properties of metal-covered windows their resistance to moisture is an important feature. All joints and seams should be tight so that no moisture can reach the wood core.

Metal-covered windows in either the double-hung or the casement type are similar in shape and appearance to wood windows. They may be made to conform to the standards of the manufacturer or according to details which are furnished by the buyer.

Hollow-metal windows are made of blue annealed steel, galvanized steel, bronze, copper, or nickel steel. They are usually of the double-hung or the casement type and are quite similar in appearance to wood windows.

Metal-covered windows are more expensive, more fire-resistant, and more durable than wood windows and more attractive than solid-section steel windows. Hollow-metal windows are more expensive than metal-covered windows. They are somewhat more fire-resistant than metal-covered windows and are much more fire-resistant than wood windows.

ARTICLE 86. GLASS AND GLAZING

Composition of Glass. Glass is composed of about six parts of white sand, one part of lime, and one part of soda with small amounts of alumina and other materials.

Classification. Glass for glazing purposes is classified as follows by Specification 123 of the Federal Specification Board:

Polished plate glass	Second silvering quality.	
	Glazing quality.	
Clear window glass	Single strength	A quality.
		B quality.
	Double strength	A quality.
		B quality.
	Heavy sheet	Glazing quality.
		Factory-run quality.
Processed glass	Chipped	No. 1 processed.
		No. 2 processed.
	Ground	Acid ground.
		Sand-blasted.
Rolled figured sheet	Figured sheet	Large variety of patterns.
	Colored figured sheet.	
Wire glass	Polished wire.	
	Polished (one side).	
	Figured.	
	Corrugated.	
	Colored.	
Ornamental	Figured plate (polished one side).	
Prism glass	Pressed tile.	
	Rolled sheet.	
	Rolled and pressed sheet.	

Definitions and Manufacture. The definitions and brief statements of the methods of manufacture of the various kinds of glass, as given by Specification 123 of the Federal Specification Board, are as follows:

Plate glass. Transparent, flat, relatively thin glass having plane polished surfaces and showing no distortion of vision when viewing objects through it at any angle. Plate glass is made at present by casting and rolling large sheets periodically or by rolling a continuous sheet. The sheets are then ground and polished.

Clear window glass. Transparent, relatively thin, flat glass having glossy, fire finished, apparently plane and smooth surfaces, but having a characteristic waviness of surface which is visible when viewed at an acute angle or in reflected light. Clear window glass is made at present by hand blowing or by machine blowing and drawing into cylinders and flattening, or by drawing directly into a sheet, the surface finish being that obtained during the drawing process.

Processed glass. There are three kinds of processed glass either in plate or window glass, viz., ground glass, chipped one process, and chipped two

processes. The ground glass is made by either sandblasting or acid etching one surface. The chipped glass is made by applying either one or two coatings of glue to the ground surface. The glue is applied hot and in cooling and drying shrinks and pulls small chips off of the surface of the glass.

Rolled figured glass. A flat glass in which the vision is more or less obscured either by the roughened surface produced in rolling or by the impression of a large variety of decorative designs in one surface of the sheet.

Wire glass. Rolled flat glass having a layer of meshed wire incorporated approximately in the center of the sheet. This glass is produced with polished or figured surfaces.

Ornamental plate. A figured plate glass made by rolling or rolling and pressing and having the plane surface ground and polished.

Prism glass. A flat glass having prism-shaped parallel ribs designed for deflecting light. This is made as a rolled plate or as a pressed plate, of which one side may be ground and polished, or as a pressed tile.

Thicknesses, Sizes, and Grades. The most common thickness of polished plate glass is $\frac{1}{4}$ to $\frac{5}{16}$ in., but $\frac{1}{8}$-in. and $\frac{3}{16}$-in. glass is fairly common. Other thicknesses up to $1\frac{1}{2}$ in. are obtainable by special order. Plate glass $\frac{1}{4}$ in. thick may be obtained in about any size up to 120 by 280 in., 144 by 260 in., or 160 by 240 in. Polished plate is available in two grades. *Second silvering quality* is used where the highest quality is desired, but most of the glass used is known as *glazing quality.*

The most common thicknesses of clear window glass are *single strength,* varying in thickness from $\frac{1}{12}$ to $\frac{1}{10}$ in., and *double strength,* varying in thickness from $\frac{1}{9}$ to $\frac{1}{8}$ in. Other thicknesses up to $\frac{1}{5}$ in. are obtainable. Single strength is obtainable in sizes up to 40 by 40 in. and double strength up to 60 by 80 in. All clear window glass should be relatively flat, but a slight regular curvature is not objectionable if it does not exceed 0.5 per cent of the length of the sheet. Glass with a reverse curve or which is crooked should be rejected. A small amount of AA quality window glass is sometimes selected for special purposes and may be obtained at a high price. The grade most commonly used in windows where appearance is an important factor is A quality, but B quality is used quite extensively. Two grades inferior to B quality are on the market. They are Fourth quality and C quality. Fourth quality glass contains many defects and distorts the objects viewed through it. It should never be used where vision is a factor. C quality is too poor for use in buildings.

Rolled figured sheet glass is made in thicknesses from $\frac{1}{8}$ to $\frac{3}{8}$ in. and can be obtained in sizes up to 48 by 130 in. It is made in a great variety

of surface finishes which obscure the vision, diffuse the light, and give decorative effects.

Wire glass is made in thicknesses from $\frac{1}{8}$ to $\frac{3}{4}$ in., the standard thickness being $\frac{1}{4}$ in. It is obtainable in sizes up to 60 by 144 in. Only one quality is manufactured for glazing purposes. It is made with polished surfaces and with a great variety of surface finishes which obscure the vision, diffuse the light, and give decorative effects. The wire is in the form of a wire mesh, the standard size of mesh being $1\frac{1}{4}$ by $\frac{7}{8}$ in. and the weight of wire No. 24 B & S gage.

The wire is placed in the glass by any of three methods: (1) by rolling a sheet of glass, placing the mesh on it while the glass is still plastic, pressing the mesh into the glass, and finishing the surface; (2) by rolling a thin sheet of glass, placing the mesh, and rolling another sheet of glass on the first sheet; (3) by placing the wire on the casting table and holding it in position while the glass is poured around it. Polished wire glass is not of the same quality as polished plate glass.

Special Glasses. A special glass, sometimes called actinic glass, has such composition that it excludes about 80 per cent of the ultraviolet rays and 50 per cent of the infrared rays of light. This glass transmits a smaller amount of radiant heat than ordinary glass.

Ordinary window glass excludes a part of the ultraviolet rays of sunlight. These rays have a beneficial effect on the health. A special quartz glass which transmits a large percentage of these rays is on the market.

Safety and Bulletproof Glass. Laminated glass, built up of layers of glass between which are cemented layers of a colorless transparent plastic resembling celluloid, is called *shatterproof* or *safety glass.* The chief use of glass of this type is in automobiles but it is also used for skylights and in the windows of asylums. *Bulletproof glass* or *bullet-resisting glass* is a thick safety glass used in banks. Ordinary safety glass is $\frac{1}{8}$ to $\frac{1}{4}$ in. thick but bulletproof glass has several laminations built up to thicknesses of $\frac{1}{2}$ in. to 2 in. The thickness most commonly used is $1\frac{1}{8}$ in. This glass will not be penetrated by bullets from most firearms which might be used, but 2-in. glass is recommended to resist shots from a 30-30 rifle. These types of glass will crack under impact but the plastic layers hold the various pieces of glass together so that it does not shatter.

Selection of Glass. Polished plate glass is used for exposed windows in the better grades of buildings. It is much superior to window glass in appearance and in the clearness of vision through it but is much more expensive. Large windows such as show windows are always made of polished plate glass.

Clear window glass is extensively used in all classes of buildings.

Chipped and ground glass are used to a limited extent where light is to be admitted but vision is to be obscured. Chipped glass is more attractive than ground glass and is used in interior partitions. Rolled figured glass serves the same purposes as chipped and ground glass, is usually cheaper, and designs which are more attractive are available.

Rolled figured glass is extensively used on the exterior and interior of buildings when it is desired to obscure the vision or diffuse the light. Many attractive designs are available and the cost is less than clear window glass.

Wire glass is used in outside windows because of its resistance to fire. When heated and drenched with water, it will crack; but, owing to the action of the wire mesh, it will remain in position and protect the interior of a building from fires originating outside. Wire glass is also used in doors and in other positions where breakage is likely to occur. It will continue to give service even though badly fractured.

Prism glass is used where it is desired to light areas which are remote from a window. Light striking the glass is deflected so that it is effective for a considerable distance away from the glass. A common use for prism glass is in the upper part of store windows where the stores are deep and windows are in the front only.

It is desirable to use some type of figured glass in basement windows below grade because such windows can not be kept clean and dirt is conspicuous on clear glass. Also the diffusing effect of figured glass is usually desirable.

Glazing. The process of placing glass in the sash is known as *glazing*. Rebates $\frac{1}{4}$ in. or more in depth are provided in the sash to support one side of the glass. After the glass is placed in position, it is held by means of putty or glazing beads, strips or molds made of wood for wood sash, and metal for metal sash, as shown in Figs. 225, 226, and 227.

Putty for wood sash should be made of linseed oil and whiting with or without the addition of white lead, as described in Art. 97. In hardening, a part of the linseed oil is absorbed by the wood in contact with the putty and the remainder hardens by oxidation.

Putty which is suitable for wood sash will not give good results when used with metal sash because the sash will not absorb linseed oil. For this reason, about 5 per cent of litharge is used in putty for steel sash to assist in the hardening by promoting the oxidation of the linseed oil. Special putty for metal sash is on the market and, if of good quality, is preferable to ordinary putty to which red lead has been added.

The puttied face of wood sash is placed outside. Before the glass is set, it is desirable to place putty on the rebate of the sash. The glass is

then pressed into the putty to an even bearing. This operation is known as *bedding*. The glass is held in position by small triangular- or diamond-shaped pieces of sheet metal called *glaziers' points* which are forced into the sash and bear against the glass. The remainder of the rebate is then filled with putty and smoothed off by use of a *putty knife*. This is called *face-puttying*. *Back-puttying* consists of forcing putty into any spaces which may be left between the edges of the rebate and the glass. Glaziers' molds are usually used instead of face putty for glass in doors.

On steel windows, the putty surface is usually on the inside but may be on the outside. In the more expensive grades of metal sash, metal molds or strips are usually used instead of face putty. The glass is preferably back-bedded and back-puttied.

Window glass may be slightly curved and still be acceptable. It should be set with the convex face out. Plate glass in large lights should be supported by a felt, leather, lead, or softwood pad near each end and should be held in position by molds which do not grip it too tightly for otherwise the glass may break.

Windows are sometimes provided with two thicknesses of glass with an air space of $\frac{1}{4}$ to $\frac{1}{2}$ in. between them. This is known as *double-glazing* and is done to reduce the heat losses, or an outer glass of polished plate or window glass is provided to protect leaded glass or glass of other ornamental design.

REFERENCES

1. KETCHUM, M. S.: "Steel Mill Buildings," McGraw-Hill Book Co., 1932.
2. "Sweet's Catalog File," F. W. Dodge Corporation.

CHAPTER XV

STAIRS

ARTICLE 87. DEFINITIONS AND GENERAL DISCUSSION

Definitions. A series of steps without an intervening platform, or *landing*, is called a *flight*. A *stair* is a series of steps, or flights of steps connected by landings, for passing from one level to another. The space in a building occupied by the stair is called the *stairway*, but this term is often used in the same sense as stair. A *staircase* includes the entire group of stairs from the bottom floor to the top floor. This term is often used with the same meaning as stair.

The various parts of a stair are shown in Fig. 229*a* and *b* and may be defined as follows:

The *tread* is the horizontal top surface of a step or the member forming this surface. The *riser* is the vertical face of a step or the member forming this face. Usually the tread projects a short distance in front of the riser forming the *nosing*. This makes a stair easier to negotiate.

The *rise* of a step is the vertical distance between treads and the *run* is the horizontal distance between risers and is equal to the width of tread, not including the nosing. The terms rise and run are also applied to the corresponding dimensions of a flight of steps. A step whose tread is narrower at one end than the other is called a *winder*. A step with one or both ends rounded in a half or quarter of a circle and ending at the newel or a step with semicircular ends with the newel at the center is called a *bullnose step*. The bottom step is called a *starting step*.

The posts set at the top and bottom of a stair and supporting the stair-rail are called *newels* or *newel posts*. The intermediate posts at turns in a stair are also called *newels*. The vertical members running between the ends of the steps and the rails are called *balusters*. The parts of a rail located at points where the direction of the rail changes without running into a newel are called *ramps, easings,* and *goosenecks* or *wreaths,* depending upon their shape, as shown in Fig. 230.

The inclined member to which the ends of treads and risers are fastened is called the *string*. An *outside string* is a string which is not located against a wall. A *wall string* is located against a wall. The upper edge of a *closed* or *curb string* is a continuous line conforming to the slope of the stairs as shown in Fig. 229*b*. If the top edge of a string

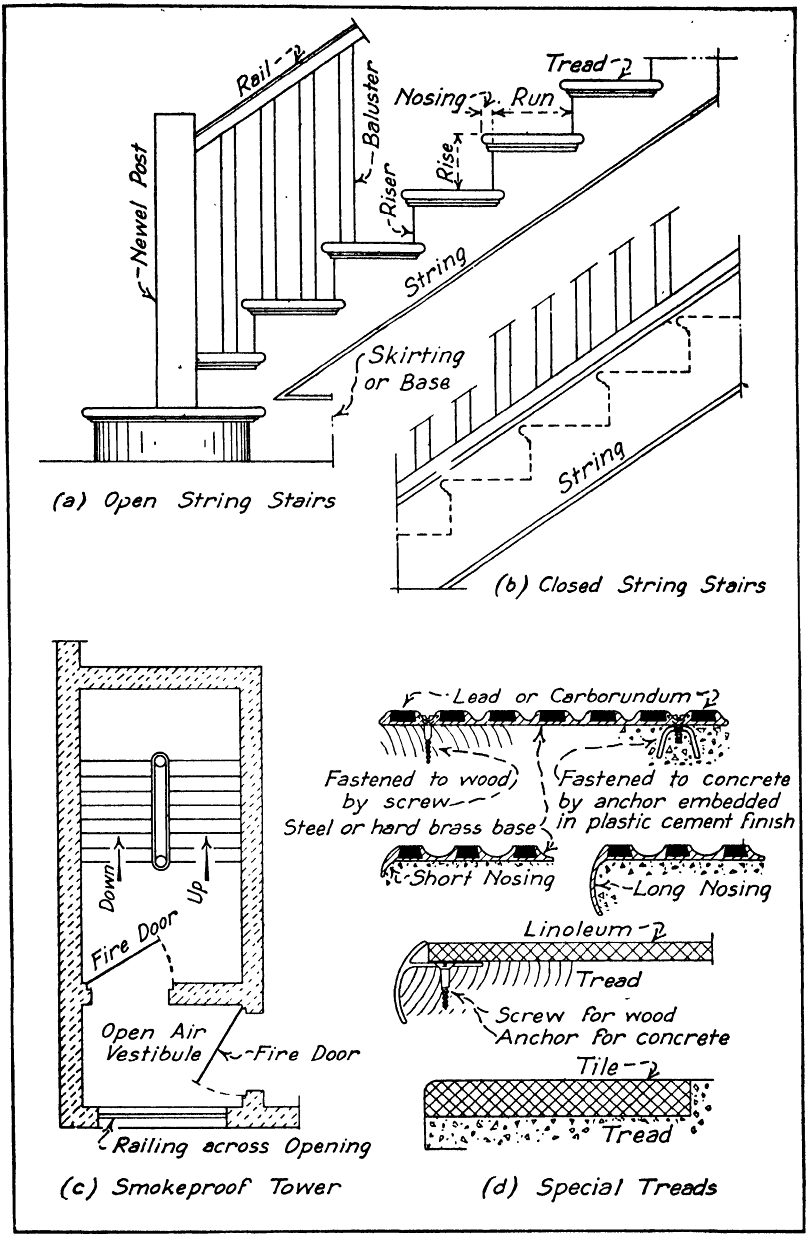


FIG. 229. Wood Stairs and Stair Details

is notched to follow the treads and risers it is called an *open string*. See Fig. 229*a*.

Inclined surfaces used for foot or vehicle traffic are called *ramps*. They are used in preference to stairs where large numbers of people are to be accommodated, as in railway stations, stadiums, etc.; in multistory garages they replace elevators, and their use for many industrial purposes is increasing. The space occupied by ramps is much greater than that required by stairs because of the flat slope which is necessarily used with ramps. The slope of ramps for foot traffic should not exceed 1 in 8, but a slope not greater than 1 in 10 is preferable. Hand rails should be provided when the slope exceeds 1 in 10. Ramps should be surfaced with some non-slip material.

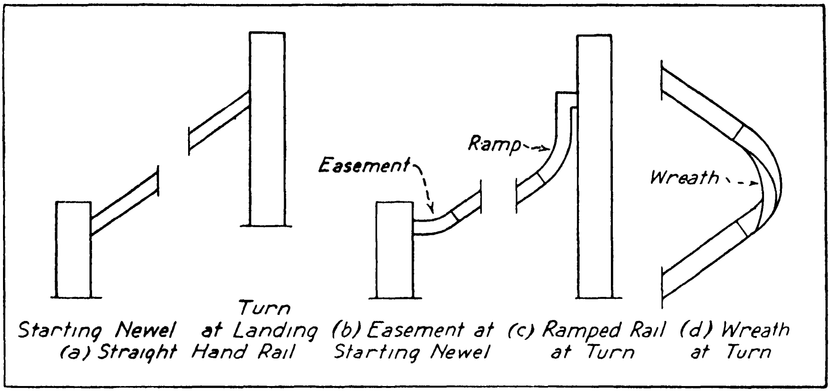


FIG. 230. Stair Rails, Easements, Ramps, and Wreaths

Proportioning Stairs. The rise and run of a stair are determined by arbitrary rules. It is recognized that, for comfort in using a stair, the run must be increased as the rise is decreased. Four of these rules are as follows:

1. The sum of the rise and run should not be less than 17 in. nor more than 18 in.

2. Twice the rise plus the run should not be less than 24 in. nor more than 25 in.

3. The product of the rise and run should not be less than 70 nor more than 75.

4. The product of the rise and the square root of the run should be equal to $23\frac{1}{2}$.

For important stairs a rise of 7 in. and a run of 11 in. will give satisfactory results; while in residences a rise of 7 or $7\frac{1}{2}$ in. and a run of 10 in.

or even 9½ in. may be used, and unimportant stairs such as those leading to basements are often made with both run and rise equal to 8 in. A rise greater than 8 in. is always objectionable. The nosing may project from ¾ in. to 1½ in.

The pitch or slope of long stairs should be made flatter than would ordinarily be satisfactory, and landings should be introduced to make the stair less tiresome and less dangerous. The flights between landings should not exceed 12 ft. in height, and the width of landing should be wider than the tread by an amount equal to the average length of step, or multiple of this length. The length of step on a landing is less than on the level and may be taken as about 2 ft. The pitch of short flights outdoors should be less than that used inside on account of the more rapid pace naturally used outdoors. A 6-in. rise and a 12-in. run are satisfactory under these conditions.

Building codes include minimum stair requirements for buildings of various types of construction devoted to various uses. For example, the minimum stair width permitted by the National Board of Fire Underwriters is 44 in., except in buildings not occupied by over 40 persons where the width may be 36 in. In places of assemblage, the aggregate width of exit stairways is required to be at least 22 in. for each 100 persons to be accommodated by such stairways. Requirements concerning the fire resistance of stairs under various conditions are included in codes.

Fire Towers. Fire towers, as illustrated in Fig. 229*c*, are stairways constructed of incombustible materials enclosed in masonry walls. Fire towers have no openings except the necessary doors and windows. Access to the stairway at each story is by vestibules or outside balconies which have solid floors of incombustible materials and which adjoin a street or a court. The doors are required to be self-closing solid doors of incombustible materials, swinging in the direction of travel from the building. The Building Code of the National Board of Fire Underwriters requires that the enclosing wall be of brick or reinforced concrete at least 8 in. thick. It requires at least one such tower in buildings exceeding 60 ft. in height; except that, in sprinklered buildings with two or more properly constructed stairways, a fire tower is not required unless the height exceeds 100 ft. Fire towers are recommended by the Code as the best known means of egress and, in addition, they afford protected facilities for attack on fires by firemen. A *smokeproof tower* is shown in Fig. 229*c*. The stairway is separated from the rest of the building by an open-air vestibule so that it can not become filled with smoke. Many arrangements, other than that shown in the figure, are possible. The design of fire towers is an important phase of building design.

Special Treads. On account of the excessive wear on stair treads, and to avoid the danger of slipping, special treads of various materials are manufactured for use on stairs. Many types of such treads, as shown in Fig. 229*d*, are on the market. One consists of an abrasive material embedded in the wearing surface of a cast-iron, bronze, or aluminum tread. In another type the abrasive material is embedded in a clay-tile tread. Strips of lead or lead slugs may be embedded in steel, cast-iron, or brass bases. Rubber, linoleum, and cork treads are used, but they should be protected by a metal nosing, as shown in the figure.

Treads and risers for steel and concrete stairs may consist of slabs of bluestone, slate, or marble. Such treads should always be supported throughout their length by steel members or concrete because if exposed to fire they may become weakened and break just when they are most needed.

Steel checkered plates and gratings may be used for the treads of steel stairs.

Railings. Stair railings may be of various designs. They may consist of a wooden rail and balusters; a wood rail and wrought-iron or steel balusters; ornamental brass, bronze, wrought iron, or steel arranged in various designs; solid plaster with wood or metal rail; pipe rails; solid stone, or brick rails; and stone railings with stone balusters. Hand rails to be used along a wall are sometimes called *grab rails*. Wide stairs should be provided with center railings.

The type of railing which is appropriate for a given stair will depend to a large extent on the type of construction used for the stair. The various types of stairs are described in the articles which follow.

ARTICLE 88. WOOD STAIRS

Several methods are used in the construction of wood stairs. One of the most common methods will be described in this article.

Rough Framing. The rough framing required for the support of a wood stair is illustrated in Fig. 231*a*. It consists of *carriages* or *horses* accurately cut to receive the treads and risers. A carriage which goes next to a wall should be kept about 3 in. away from the wall so that it will not interfere with the wall string to be placed later. Carriages are constructed of 2-in. or 3-in. material and should be of sufficient strength to carry the load which they are to receive. They are usually spaced 12 in. center to center. On long flights, *false risers* are used on every fifth or sixth step to stiffen the structure. In this case, the carriages should be cut so that this riser will clear the finished riser. Rough treads are placed so that the stairs may be used during construction, but these are removed before the finished treads are placed.

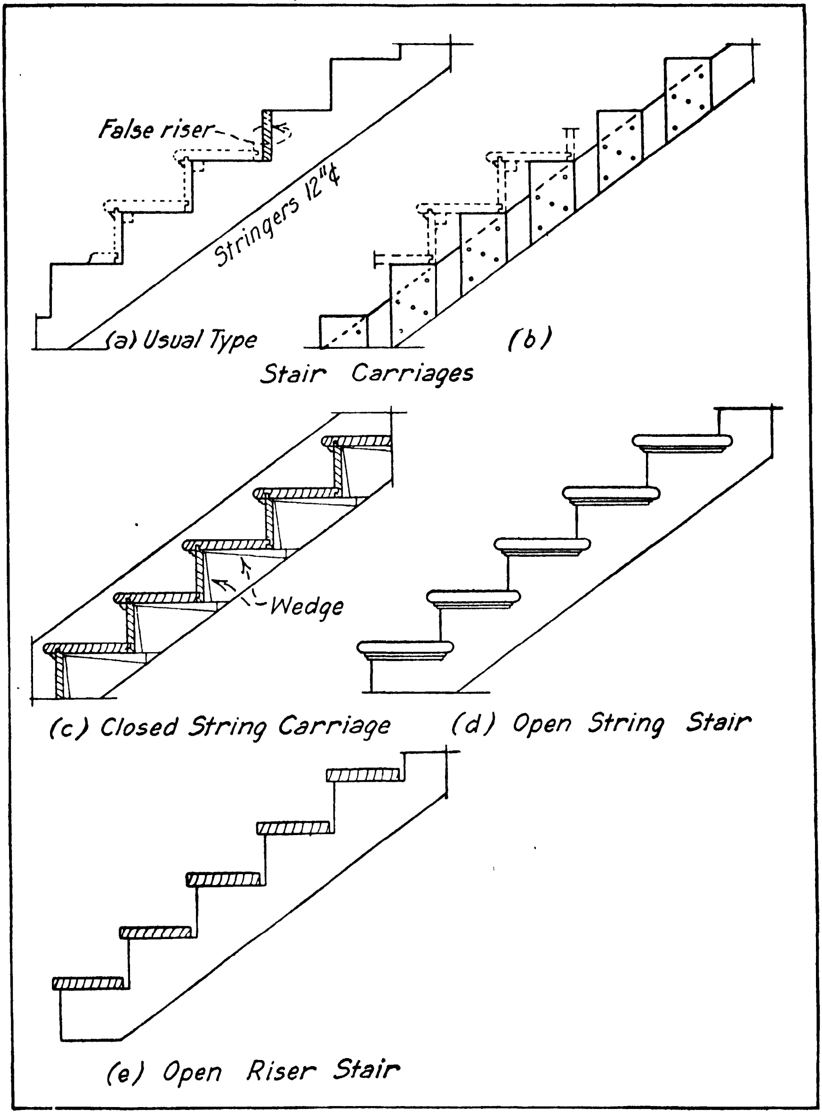


FIG. 231. Types of Wood Stairs

Occasionally carriages are constructed as shown in Fig. 231*b*, but this type is undesirable.

Finished Stairs. The finished stairs are prepared at the mill and are placed after the plastering is completed. The ends of the finished treads and risers are housed in a wall string or closed string, as shown in Fig. 231*c*, provision being made for wedges which are driven up tight and glued to hold the treads and risers firmly in place.

Open-string construction is illustrated in Fig. 231*d*. The string is cut to receive the treads and risers; the nosing is mitered and returned to finish the exposed end of the tread; the riser is mitered with the string; and the lower end of the balusters is dovetailed or doweled to the tread. Tongue-and-groove joints are usually provided at the junctions of the risers and treads, and blocks may be glued or screwed in the interior angle between the risers and treads.

The treads should usually be $1\frac{1}{8}$ in. thick and the risers $\frac{7}{8}$ in. thick.

Materials. On account of the severe wear to which treads are subjected they should be made of oak, birch, maple, or yellow pine. Oak and yellow pine should preferably be quarter-sawed. The risers and other parts of the stair may be of softwood if desired.

Plank Stair. A rough stair constructed of planks is illustrated in Fig. 231*e*. It is of open riser construction with plank treads notched in plank strings.

ARTICLE 89. CONCRETE STAIRS

Reinforced-concrete stairs are extensively used in fireproof buildings. They are usually placed after the structural frame has been completed; so recesses and ties should be provided in the structural frame to receive the stairs.

Structural Details. A simple flight of reinforced concrete is illustrated in Fig. 232*a*; a flight ending at a landing in Fig. 232*b*; a flight beginning at a landing in Fig. 232*c*; and a flight beginning and ending at a landing in Fig. 232*d*. Particular attention should be paid to the position of reinforcement at an interior angle on the tension side. If the reinforcement follows around the tension side of the stair slab at the angle, it will tend to straighten out and separate from the slab. The drawings show how this can be avoided. In Fig. 232*b* to *d*, the stair and the landing act together as a bent slab supported at each end. Instead of being designed as an integral part of the stair, the landing may be supported by beams running between walls enclosing the stairs, by beams suspended from the structural frame of the floor above, or by beams supported by props resting on the structural frame of the floor

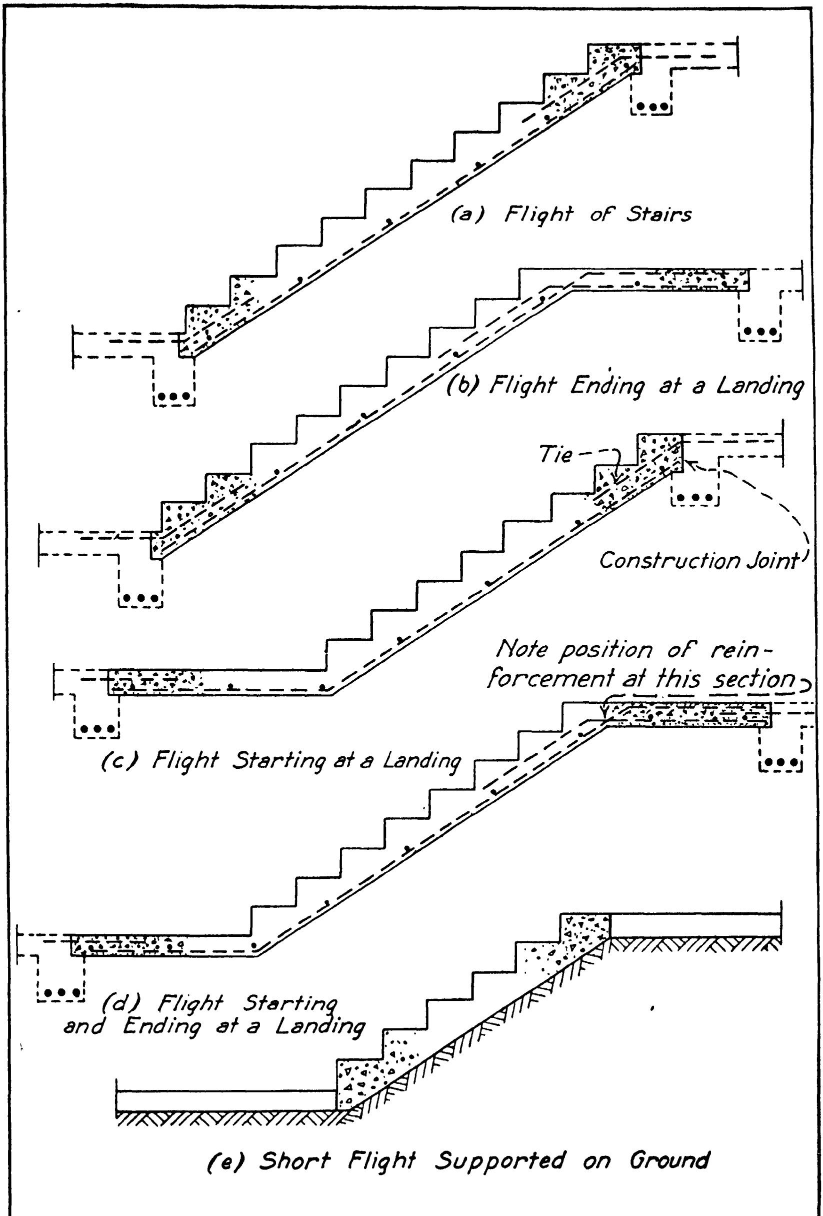


FIG. 232. Concrete Stairs

below. Short flights are frequently supported on the ground, as shown in Fig. 232*e*.

Concrete is probably the most suitable material for stairs of complicated design, such as winding stairs. Circular or spiral stairs similar to the stone stairs shown in Fig. 237*a* are constructed of precast steps.

Details of Steps. Various details of steps are illustrated in Fig. 233. The simplest type of step has a vertical riser, and the tread is without a

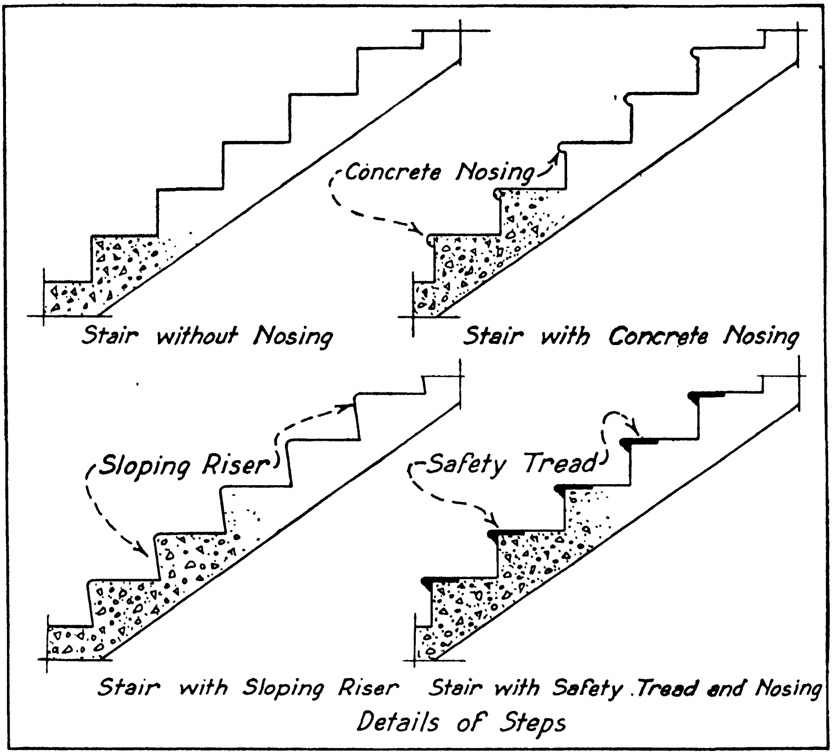


FIG. 233. Types of Concrete Stairs

nosing, but this detail should not be used on important stairs. Unless proper precautions are taken, the form boards for the risers in the stairs with concrete nosings may swell and crack off the nosings. To avoid this, the tops of the boards should be beveled and the boards should be removed as soon as possible. Oiling the boards also helps. The effect of a nosing can be secured at little expense by sloping the riser outward at the top. One form of cast-iron tread provides the nosing and thus simplifies the formwork. The nosing can be formed of concrete and

can be used with or without a special tread. Other types of treads, as described in Art. 87, can be used with concrete stairs. A terrazzo finish is frequently used on concrete stairs where appearance is an important factor.

ARTICLE 90. STEEL AND CAST-IRON STAIRS

Steel stairs are of three general types. The simplest type consists of strings of steel channels and treads of steel checkered plate, concrete supported on steel angles or channels, or steel grating, as shown in Fig. 234*a*. The risers are usually open and the treads are fastened to the strings by light shelf angles. The railings and posts may be of angle irons or a pipe rail may be used. Stairs of this type are suitable for use in industrial buildings.

Another type of steel stair consists of strings of steel channels or plates, and risers and structural treads formed of steel plates, all finished in such a manner as to be suitable for use in high-class buildings. Typical details of this type of stair are shown in Fig. 234*b*, but a large number of designs are on the market. Stairs of this type are supplied by manufacturers making stair-building a specialty. The illustration shows treads of various materials supported by the sub-tread consisting of a steel plate. The railings in this type are made attractive in design to suit the rest of the stair.

The third type consists of steel strings and precast reinforced-concrete combination tread and riser as shown in Fig. 234*c*. Spiral stairs as shown in Fig. 235 are only suitable for use where they will receive very little traffic and where the space available is small. They are commonly made of cast-iron winders arranged around a pipe newel, but types consisting of cast-iron treads and steel winders are on the market.

ARTICLE 91. STONE AND BRICK STAIRS

Method of Support of Stone Steps. Stone stairs may consist of steps supported at both ends by masonry walls, as shown in Fig. 236*a*. One end may be built into a masonry wall leaving the other end free forming *hanging steps*, as shown in Fig. 236*b*; or the stair may be circular in plan with winders, the outer end being supported by a wall and the other by a central newel formed by the inner ends of winders, as shown in Fig. 237*a*.

Shape. Steps may be approximately rectangular in cross-section, as shown in Fig. 236*c*; or approximately triangular in section, as shown in Fig. 236*d*, each step bearing about 2 in. on the step below. The steps with triangular cross-section are called *spandrel steps* and have the advantage of being lighter in weight and more attractive in appearance

when the under side called the *soffit* is exposed. The ends of spandrel steps are made rectangular in cross-section where they are built into the supporting wall.

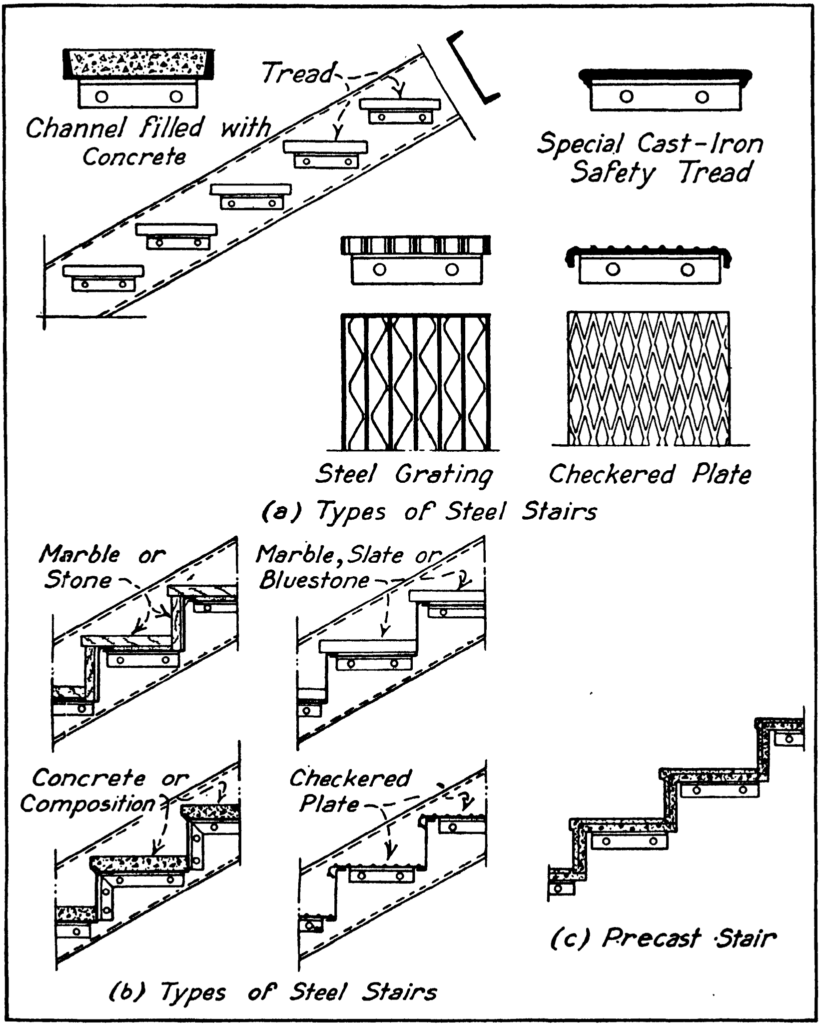


FIG. 234. Types of Steel Stairs

Hanging Stairs of Stone. The method of support of hanging steps may need further explanation. Each step is supported at one end by the wall in which it is embedded and at the free end by the step below,

on which it rests. If the support at the wall were sufficiently rigid, this design would be satisfactory, but a slight yielding at the wall would permit the steps to move in the horizontal direction. This is prevented by notching the steps, as shown in Fig. 236b, so that each step is restrained from moving horizontally and vertically. The top and bottom

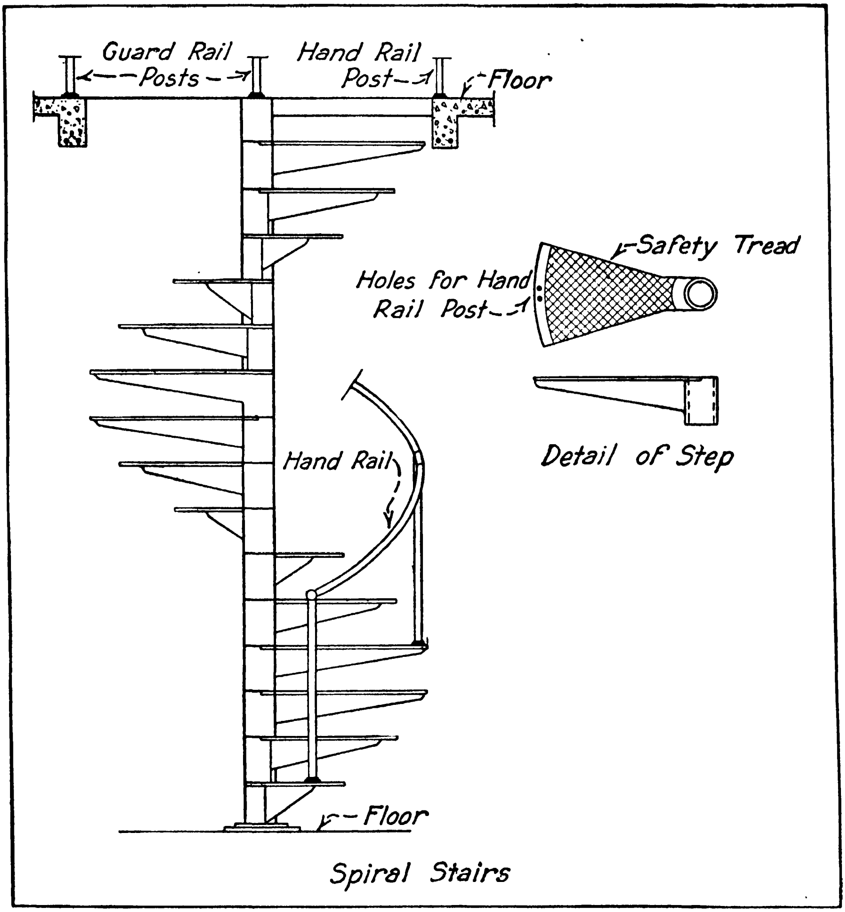


FIG. 235. Cast-Iron Spiral Stairs

of the stair must be arranged to resist horizontal movement, and the bottom must carry the accumulation of vertical load from all of the steps.

For long flights it may be necessary to provide additional support for the free end by means of a bracket or steel cantilever beams projecting from the wall at intervals; or a steel or reinforced-concrete stringer may

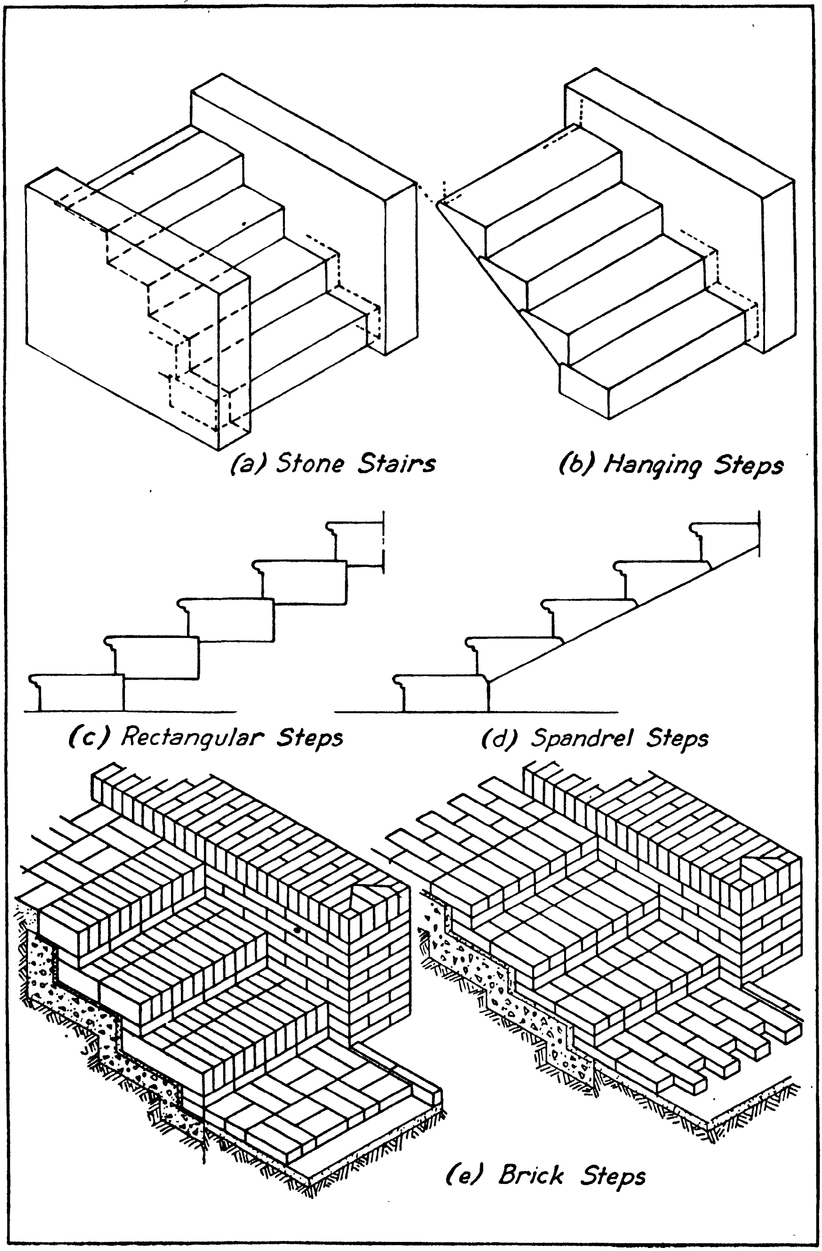


FIG. 236. Stone and Brick Steps

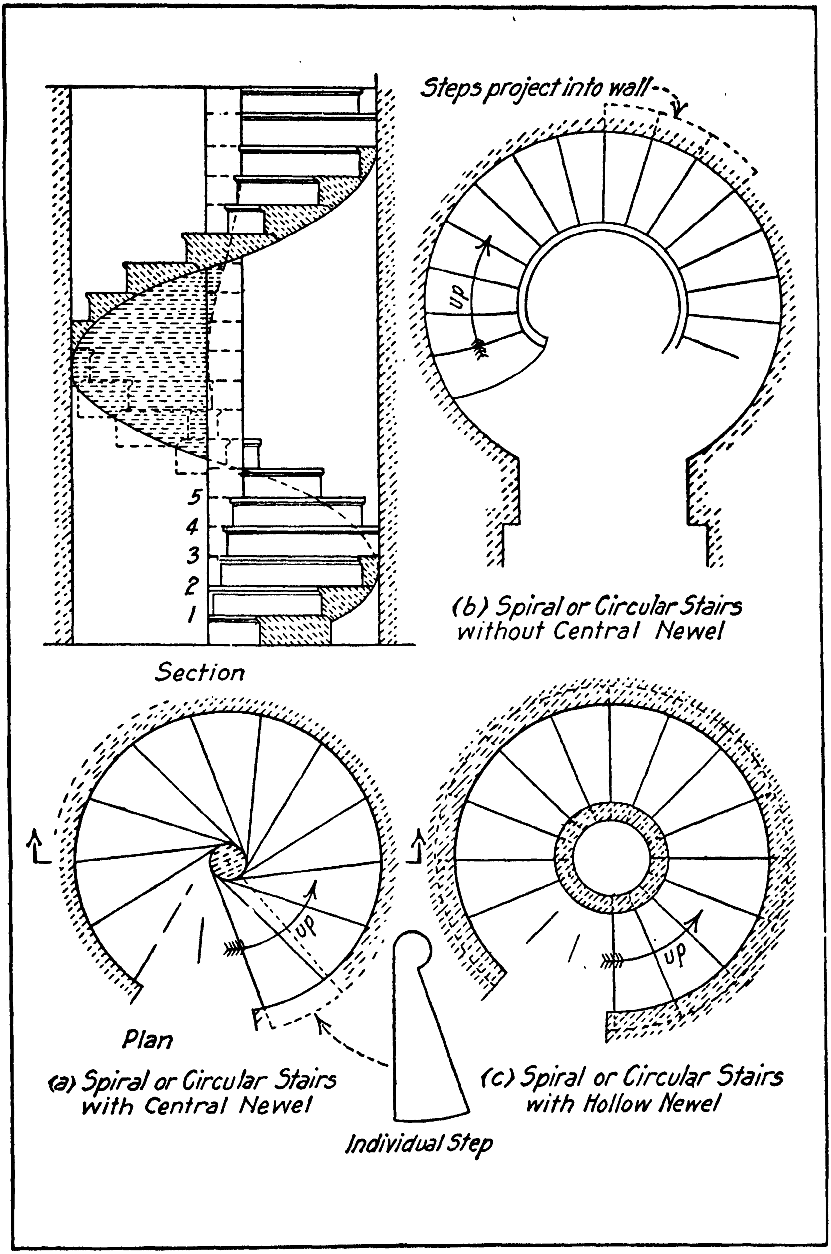


FIG. 237. Stone Spiral or Circular Stairs

be used, in which case the stair is no longer of the hanging type. Hanging steps are always of the spandrel type because they are lighter and because of the more attractive soffit which they form.

A special example of the hanging stair is that of the circular stair with an open well instead of a newel, as shown in Fig. 237*b*. A spiral stair with a hollow newel is shown in Fig. 237*c*.

Placing the Steps. The ends of the steps may be built in the masonry walls as the work progresses, they may be supported on corbels, or recesses may be left in the walls to receive the steps which may be placed later. It is evident that corbels can not be used with hanging steps and that great care must be taken in securing the ends if these steps are placed in recesses. In any case, the free ends of hanging steps should be supported until the mortar has thoroughly set.

Outside steps should be placed with the treads pitched slightly forward to provide a wash in order that they will drain properly.

Kind of Stone. The stone used for steps must have superior wearing qualities. Granite is the most satisfactory in this respect, but some sandstones, limestones, and marbles may be used with good results. Stone used for outside steps is subjected to severe weathering action.

Brick Steps. Short flights of brick steps supported by concrete are used outdoors to a considerable extent. Two methods of construction are illustrated in Fig. 236*e*. The steps should pitch forward with a slope of about ¼ in. per ft. to provide drainage; they should be hard, durable brick laid in rich cement mortar with a slightly concave joint thoroughly rubbed with a steel jointing tool. The front of the treads should be laid of full headers.

REFERENCES

1. Building Code, National Board of Fire Underwriters, 5th Ed., Revised Reprint, 1934.
2. "Sweet's Catalog File," F. W. Dodge Corporation.

CHAPTER XVI

PAINTS AND OTHER PROTECTIVE COVERINGS

ARTICLE 92. DEFINITIONS AND GENERAL DISCUSSION

Paint, varnish, enamel, and lacquer are materials applied in the liquid form to the surface of wood, metal, brick, or other materials to form a thin coating or film which solidifies. This coating is applied for one or more of the following reasons: to protect from the elements and from wear; to improve the appearance and give the desired color and finish; to facilitate cleaning; or to improve the lighting of interiors of buildings. Stains are applied to wood surfaces to produce the desired color, to emphasize the grain, or to protect the wood. Metal surfaces may also be galvanized, sherardized, tin-plated, terne-plated, chrome-plated, or nickel-plated for the purpose of protection or to improve their appearance.

Paint is a mixture of a vehicle and a pigment. The *vehicle* is the liquid portion of the paint, and the *pigment* consists of solid particles added to give color and durability to the paint. Oil paints usually have linseed oil as the principal constituent of the vehicles, but a *volatile thinner* such as turpentine is added to make the paint spread more readily and a *drier* is added to accelerate drying. During the process of drying, practically all of the turpentine evaporates and little of it appears in the resultant product; the linseed oil becomes oxidized and hardens, binding the pigment together; and the pigment remains practically inert although some pigments act as driers.

Water paints consist of a solid material such as portland cement, slaked lime, or whiting to which water is added forming a liquid mixture which can be applied to a surface with a brush. The mixture of lime and water is known as *whitewash,* and that of whiting and water, as *calcimine.* Other materials may be added to increase the adhesion of whitewash and in the case of calcimine these materials must be added because whiting itself will not adhere to a surface. Calcimine hardens simply by the evaporation of the water but the calcium hydroxide of whitewash absorbs carbon dioxide from the air and forms calcium carbonate.

There are two main classes of varnish, the distinction between the two being largely in the vehicle. The two classes are oil varnish and spirit varnish.

Oil varnish consists of resin and a drying oil such as linseed oil or China (Chinese) wood oil which is thinned with a volatile liquid such as turpentine to which a drier has been added. Perilla oil has been used considerably during recent years and oiticica oil and dehydrated castor oil are being used as a partial substitute of China wood oil. Varnish dries by the evaporation of the thinner and the oxidation of the oil, leaving a hard coating consisting of the resin and oxidized oil. Varnish is transparent and, since no pigment is used, it has the clear amber color given by the oil and resin. Some varnishes are practically colorless.

Spirit varnish consists of resin dissolved in some volatile oil which evaporates after the varnish is spread, leaving a coating of resin only.

Enamels are paints with varnish as a vehicle and various pigments to give the desired color.

Lacquers usually consist of a nitrocellulose base to which certain gums, solvents, and pigments have been added.

Wood stains consist of a coloring material and a liquid which is composed of a drying oil and a thinner such as linseed oil and turpentine in the case of oil stains, water in the case of water stains, and alcohol in the case of spirit stains. The primary functions of stains are to color wood and to emphasize the grain.

The surface of paint may have a gloss finish, a semigloss or eggshell finish, or a flat, matte, or dull finish, depending largely upon the relative amounts of oil and turpentine used in the vehicle. Most pigments have no gloss and if mixed with turpentine, which simply evaporates, they will form a coating without gloss. However, some drying oil such as linseed oil must be used as a binder and linseed oil dries with a glossy finish, so the amount of gloss depends upon the amount of linseed oil present. If a high gloss is desired 1 part turpentine to 4 parts oil might be used, but if a flat finish is desired the proportions would be about 1 part oil to 3 parts of turpentine. Benzene has the same effect as turpentine.

Varnishes naturally dry with a gloss finish and since enamels have varnish as a vehicle they also dry with a gloss finish. Flatting varnishes have a dull finish generally due to wax incorporated in the varnish. Tung oil which has not been heated to too high a temperature dries flat and may be used in place of linseed oil in flattening varnish. Extender pigments, such as diatomaceous earth, and soaps, such as aluminum stearate and zinc stearate, are also used to make varnishes flat. The gloss finish may be removed from varnish by rubbing with powdered pumice stone and water after it has hardened.

Paint may be prepared by a painter from the raw materials or it may be obtained *ready-mixed* or *prepared* ready for use. If a painter is to

do the mixing, linseed oil paint of any color is usually prepared by first making a white paint and then securing the desired color by adding the proper coloring pigments. Nearly all pigments are furnished in paste form ground in linseed oil. The white paint is usually made by *breaking up* white lead paste and zinc oxide paste separately, by adding linseed oil, and working and stirring each with a wooden paddle, forming a thick liquid of uniform consistency. The zinc oxide is then added to the white lead in the proper proportions. To this mixture is added the color pigment which has been broken up in oil. The drier is added, then the remainder of the oil, and finally the turpentine, with continual stirring during the entire process.

Varnish and enamel are furnished ready for use by the manufacturers and should not be altered in composition by the painter.

Paints having water as a vehicle are often referred to as *distemper paints.*

Paint and varnish are usually applied with a bristle brush, but the air spray is extensively used. Small articles may be coated by dipping into vats containing paint.

Terms Relating to Paint Specifications. The following definitions have been adopted by the American Society for Testing Materials and appear in the 1939 Standards:[7]

Paint. A mixture of pigment with vehicle, intended to be spread in thin coats for decoration or protection, or both.

Varnish. A liquid coating material, containing no pigment, which flows out to a smooth coat when applied and dries to a smooth, glossy, relatively hard, permanent solid when exposed in a thin film to the air. Some materials possessing the other characteristics dry without the usual gloss and are termed *flat varnish.*

According to the definition of paint, a mixture of pigment and varnish is a paint, and on the other hand a solution of stain in oil or varnish, no pigment being present, is not a paint.

Enamel. A special kind of paint which flows out to a smooth coat when applied and dries to a smooth, glossy, relatively hard, permanent solid when exposed in a thin film to the air. An enamel always contains pigment and has a considerable hiding power and color. Some enamels dry to a flat or eggshell finish instead of a gloss finish.

Pigment. The fine solid particles used in the preparation of paint, and substantially insoluble in the vehicle. Asphaltic materials are not pigments except when they contain substances substantially insoluble in the vehicle in which they are used.

Vehicle. The liquid portion of a paint. Here anything that is dissolved in the liquid portion of a paint is a part of the vehicle.

Volatile thinner. All that liquid portion of a paint, water excepted, which is volatile in a current of steam at atmospheric pressure.

Non-volatile vehicle. The liquid portion of a paint excepting its volatile thinner and water.

Drying oil. An oil which possesses to a marked degree the property of readily taking up oxygen from the air and changing to a relatively hard, tough, elastic substance when exposed in a thin film to the air.

Drier. A material containing metallic compounds added to paints and painting materials for the purpose of accelerating drying.

Size. In the painting art, a liquid coating material, intended to close the pores, used to prepare a surface for further treatment. It is not regarded as a finishing material.

Filler. A special kind of paint used for filling pores or other small breaks in the continuity of a surface to render it smooth preparatory to further treatment. When applied and exposed to the air, a filler should dry to a relatively hard, permanent solid capable of properly supporting subsequent coats.

Covering power. The use of this term should be avoided if possible. This term has been used so loosely that it might mean hiding power, spreading power or the simple property of producing a coat.

Hiding power. The power of a paint or paint material as used to obscure a surface painted with it. In this definition the word *obscure* means to render invisible or to cover up a surface so that it can not be seen.

Spreading rate. The rate at which a paint material, as used, is brushed out to a continuous uniform film expressed in terms of the area to which a unit volume, as used, is applied. This term must not be confused with the much abused term *spreading power.* The use of the term spreading rate is illustrated in the following sentence: " The paint when spread on a planished iron surface at the rate of 600 sq. ft. to the gallon will not sag or run when placed in a vertical position at 70 deg. fahr."

Other terms included in these Standard Definitions are: Standard, Equal to, Pure, Commercially Pure, Adulteration, Adulterant, Opacity, Fineness, Crystalline, Amorphous, Toner, Lake, Semi-drying Oil, Non-drying Oil, Tinting Strength, Color, Tint, Shade, Hue, Tone, Drying, Specific Gravity, Density, Gallon, Water, and Dry.

ARTICLE 93. DRYING OILS, VOLATILE THINNERS, AND DRIERS

The terms drying oil, volatile thinner, and drier have been defined in the preceding article.

Drying Oils

The most important drying oil used in paint and varnish manufacture is linseed oil, but China wood oil or tung oil and perilla oil are quite extensively used and their use is increasing. Drying oils of minor importance are poppyseed oil, soybean oil, oiticica oil, dehydrated castor oil, and fish oil.

Linseed Oil. Linseed oil is made by pressing crushed or ground flaxseed (linseed) without heating, as in the *cold-pressed process;* by pressing ground flaxseed which have been heated to a temperature of 160 to 180 deg. fahr., as in the *hot-pressed process;* by forcing the ground flaxseed against a conical grating by means of a screw, the oil passing through the grating and the pressed meal coming out of the end of the grating, as in the *continuous-expeller method;* or by extracting the oil from the ground flaxseed by leaching with petroleum naphtha and then distilling the naphtha from the oil, as in the *extraction process.* The hot-pressed oil is the most extensively used. The oil produced by those processes is filtered and allowed to stand in order that *foots,* which cause it to be cloudy, may settle out. When raw oil is heated above 350 deg. fahr. it may thicken and become cloudy and is said to *break.* This tendency may be overcome by allowing the oil to age by standing for a long period or by refining. Oil which is used in varnish manufacture must not break.

The drying of linseed oil is not due to evaporation of the oil but primarily to the absorption of oxygen from the atmosphere. This oxidation may be hastened by heating the oil to 350 deg. fahr. or higher and then cooling, by the addition to the oil of certain materials known as driers, or by a combination of these two methods which produces what is called *boiled oil,* although the oil does not actually boil in the process. The driers commonly used consist of linoleates, resinates, or borates of lead and manganese made as described under the heading of driers. Linseed oil which has dried or oxidized is known as *linoxyn.* It is a relatively hard, tough, elastic substance. The drying of a film of raw oil requires several days but boiled oil will dry in less than a day under proper conditions. Boiled oil is inferior to raw oil in durability, elasticity, and penetrating power and since it is darker than raw oil it is not as satisfactory as raw oil for use as a vehicle for white or light-colored paints.

Raw linseed oil to which driers have been added without heating is known as *bunghole oil* and is an inferior product.

The color of linseed oil varies from pale yellow to amber and often has a tinge of green or red. The color of the darker oils may be cleared up considerably by exposing to sunlight or by a bleaching process which consists of adding sulphuric acid to the oil and blowing air through it at the same time. Certain impurities gradually settle to the bottom and after the oil is washed with water to remove the sulphuric acid, and filtered, it is much paler in color and is known as *bleached oil.* The use of bleached oils for light-colored or white paints on exterior work exposed to sunlight is of questionable value since the sunlight soon

bleaches the paints made with the unbleached oil so that these are as light as the paints made from bleached oil. Bleached oil is not as durable as ordinary oil and is more expensive.

China Wood Oil. China wood oil is also known as *tung oil.* It is made by pressing the nuts of the tung tree found in China. Raw tung oil dries very rapidly forming an opaque waxlike inelastic film and so is not suitable for use in paint and varnish. By heating the oil and adding suitable materials these objectionable properties are overcome, the treated oil forming a film which is glossy and more durable, more resistant to wear, more impervious to water but less elastic than the linseed oil film. The treated oil dries more slowly than the raw oil. Tung oil is extensively used with linseed oil. It is used in the manufacture of varnish and enamel. Cement floor paint is commonly made of China wood oil and a hard resin.

Other Drying Oils. *Poppyseed oil* is a clear colorless oil made from poppy seeds. It is desirable for use in the lighter-colored paints but due to its high cost it is used only for artists' colors.

Soybean oil produced by pressure from the soy bean is a drying oil which is not used alone but is used with linseed oil as an adulterant to reduce the cost. Soybean oil is really a semidrying oil because it should not be used alone on account of its long *after tack.* Combination of soybean oil with linseed and China wood oil, or with perilla oil and China wood oil, will produce a satisfactory drying oil mixture. *Fish oil* or *menhaden oil* is obtained from the menhaden fish by boiling or by pressure. When treated with a suitable drier it makes a satisfactory drying oil which is quite resistant to weathering and to the action of heat. It has an objectionable odor and can not be used indoors. Some specially refined treated fish oils which are on the market will dry as rapidly as linseed oil without the use of driers.

Driers

Driers are materials containing metallic compounds added to paints and painting materials for the purpose of accelerating drying. They usually consist of the linoleates, resinates, or tungates of lead and manganese. These are organic compounds produced by adding lead and manganese salts to hot linseed oil, resin, or tung oil, respectively, and thinning with turpentine or benzene. Driers produced in this way are called *japan driers* or *japans.* A drier when added to a drying oil acts as a medium for the transference of oxygen from the atmosphere to the oil thus causing the oil to harden. Unfortunately, driers do not cease to act after the oil has dried but may cause oxidation to continue until the film has been destroyed.

Oil driers are inorganic compounds used only as driers for linseed oil. The oil driers commonly used are litharge and red lead or minium, which are oxides of lead, lead borate, lead acetate, and manganese dioxide. These driers may be added to cold oil as in bunghole boiled oil, or the mixture of the oil and drier may be heated, thus producing boiled oil. Cobalt drier is also used.

Volatile Thinners and Solvents

Turpentine. The principal thinner or solvent used in paint and varnish is turpentine. It is made chiefly by distilling balsam, which is the resin obtained from pine trees. The residue left after the turpentine has been distilled off is rosin. Turpentine obtained in this way from balsam is also called spirits of turpentine, oil of turpentine, sap turpentine, and gum spirits. Wood turpentine is another product and is obtained by the distillation of scrap wood such as sawdust and tree stumps containing resin instead of the balsam from the living trees. Wood turpentine which has been refined is satisfactory for use in paint and varnish.

Turpentine is a clear volatile liquid the chief use of which is in thinning linseed oil paint and varnish to facilitate spreading, to increase their ability to penetrate into the pores of wood, and to hasten drying. Turpentine is also used as the principal component of the vehicle of "flat" paints. Such paints dry without gloss and are used as a final coat over linseed oil paints. Sufficient linseed oil must be used in flat paints to bind the pigment, but the quantity required for that purpose is small. Pure turpentine evaporates without leaving a residue, but commercial turpentine leaves a slight deposit of resin.

Turpentine Substitutes. Since the chief function of turpentine is to facilitate the application of paint and considering that it evaporates during the drying process, other volatile liquids which are less expensive are frequently substituted for turpentine. The most common of these are benzene, which is obtained from the distillation of certain petroleum oils; and benzol (benzene) and solvent naphtha, which are obtained from the distillation of coal tar.

Other Volatile Thinners. Other volatile thinners are grain (ethyl) alcohol, denatured alcohol, and wood (methyl) alcohol, which are used in shellac varnishes; amylacetate (banana oil), which is used as a solvent for nitrated cotton in making nitrocellulose lacquers; and carbon bisulphide, which is used in some bituminous varnishes and has a strong and very objectionable odor.

ARTICLE 94. PIGMENTS

Classification.[3] The various pigments in use may be roughly divided into (*a*) body pigments — those which constitute the bulk of the pigment present and give to the paint film its characteristic properties; (*b*) color pigments — those used primarily to produce a decorative effect; and (*c*) extenders — those substances which have few, if any, of the properties required of body pigments but which, on account of their cheapness, are added to paints, in many cases without harmful effects. There is no sharp distinction between these classes since many color pigments serve to give both body and color to a paint. Many substances that may be classed as extenders were formerly considered solely as adulterants, although now it is recognized that, in some cases, at least, the use of certain extenders may improve the quality of a paint.

The white pigments are used in making white paint for use directly or as a base for colored paints which are given the desired color by adding the proper color pigments, but when very dark-colored paints are desired they are usually made directly from the color pigments. In making white paints, a white pigment or a combination of white pigments is mixed with linseed oil, a volatile thinner such as turpentine, and a drier.

White Pigments

Basic Carbonate White Lead, $2PbCO_3 \cdot Pb(OH)_2$. White lead is a body pigment in the form of a white powder but for convenience in use it is mixed with a small percentage of linseed oil by the manufacturers to form a thick paste.

White lead is manufactured by several processes, the oldest and most important being the *Old Dutch process.* In this process metallic lead in the form of perforated disks about 6 in. in diameter is placed in earthenware pots in the bottom of which, but not in contact with the lead, is placed acetic acid. These pots are stacked in tiers with a layer of tanbark between tiers. The tanbark gradually ferments, generating heat and giving off carbon dioxide gas. Under the action of this heat the acetic acid is vaporized and attacks the lead, converting it into basic lead acetate. The carbon dioxide gas formed by the tanbark finds its way into the pots and converts the basic lead acetate into basic lead carbonate, which is white lead, and releases acetic acid for the further continuation of the process, which lasts about three months. The white lead thus formed is a flaky substance which is crushed, screened, washed, and ground in oil, forming a paste which is ready for the market.

Other processes are the *Carter process* in which lead in the form of granular dust is treated with acetic acid, forming the basic acetate which is converted to the basic carbonate by carbon dioxide; and the *precipitation process* in which lead is dissolved in acetic acid in the presence of air producing basic lead acetate, and the basic carbonate is precipitated from the acetate solution by carbon dioxide.

White lead when mixed with linseed oil forms a paint which hides well and has a good spreading power but is blackened by air containing compounds of sulphur and has a tendency to chalk or change to a powder. This tendency to chalk may be overcome by adding zinc oxide but, since zinc white has a tendency to crack and chip, care must be used in proportioning these materials. The surface of white lead paint is softer than that of zinc oxide paint and takes up dirt more readily. Other names by which basic carbonate white lead is known are corroded lead, corroded white lead, hydrate of lead, lead carbonate, hydrocarbonate of lead, and lead.

Basic Sulphate White Lead, $(PbSO_4)_2 \cdot Pb(OH)_2$. Basic sulphate white lead is different in composition but similar in properties to basic carbonate white lead. It is not usually so white as the best basic carbonate but is not discolored to so great an extent by sulphur compounds present in the atmosphere. Specifications often permit the use of either the carbonate or the sulphate.

Basic sulphate white lead is made by oxidizing with air the fumes produced by roasting and vaporizing galena ore, which is lead sulphide, PbS. The white fumes thus formed are collected in large bags which permit the air and gas to escape through the meshes of the bag material and retain the basic sulphate white lead which is in the form of a white powder. Other names for basic sulphate white lead are sublimed lead, sublimed white lead, sulphate of lead, or white lead. This material must not be confused with sulphate of lead ($PbSO_4$) which is very inferior material.

Zinc Oxide, ZnO. Zinc oxide or zinc white, a body pigment, is a fine white powder but for convenience in use it is mixed with linseed oil by the manufacturers to form a paste.

In making *French process* zinc oxide, metallic zinc is vaporized by heating and the fumes thus formed are oxidized by the air producing a fine white powder which is deposited in long chambers. The particles of zinc oxide are deposited in the order of their size, the larger particles being deposited as the fumes enter the chambers, and the smaller at the farther end. The finest particles are the whitest and are known as "white seal," the next are "green seal," and the coarsest are "red seal." *American process* zinc oxide is made by roasting the sulphide or

carbonate ores of zinc and may not be as white as the French process zinc oxide. When mixed with linseed oil zinc oxide forms a paint which is very white, has a good hiding power, and spreads well. It is not darkened by air containing sulphur compounds, and if it were not for its tendency to crack it would make an ideal paint. This tendency to crack is avoided by mixing with white lead, as explained. Zinc oxide forms a harder surface than white lead so does not get dirty as readily. It is used alone as the pigment in high-grade white enamels. Zinc oxide is also known as white zinc, and zinc.

Lithopone. Lithopone is a white powder composed of barium sulphate and zinc sulphide made from the precipitate formed by adding a solution of barium sulphide to a solution of zinc sulphate. It is a body pigment. Paints made from lithopone will not stand outdoor exposure but may be successfully used indoors. Lithopone is the whitest pigment known and is extensively used in cheap enamels and in flat wall paints which dry without a gloss. Inferior grades turn gray in sunlight but change back to white in the dark. Lithopone reacts with white lead pigment to form black lead sulphide so these pigments are not used together.

Barium Sulphate (Barytes and Blanc Fixe), $BaSO_4$. This is a widely used extender formed either by grinding the natural mineral barytes or by precipitation by treating a solution of barium chloride with a solution of sodium sulphate. The natural sulphate is known as *barytes* and the precipitated sulphate as *blanc fixe* and *permanent white.*

Barium sulphate is an inert white material which has little hiding power when mixed with oil. It is used to dilute white and colored paints and many claim that it improves the quality of the paint when used in proper proportions.

The form obtained by precipitation is known as *lake base,* for it is extensively used as a base on which colors are precipitated in forming the pigments called *lakes.*

Magnesium Silicate (Asbestine). Magnesium silicate when used as a pigment is made by grinding asbestos and is known by the trade name of *Asbestine.* It is a white pigment, classed as an extender whose chief function is to prevent the settling out of other pigments when paint is left standing.

Calcium Carbonate (Whiting), $CaCO_3$. The calcium carbonate used as a pigment is made by grinding and washing natural chalk, allowing it to settle, and then drying. It is graded according to fineness into Paris white, gilders' whiting, and commercial whiting. Paris white and gilders' whiting are very fine and are used to neutralize any acid which may develop in paint and to aid in holding the other pigments in suspension.

Commercial whiting is used in the water paint known as calcimine and in making putty by mixing with linseed oil. Calcium carbonate may be made by treating lime water with carbon dioxide forming a precipitate. In this form it is used in making putty but is not used extensively as a pigment.

Silica (Silex), SiO_2. Silica when used as an extender pigment is made by crushing and grinding white sand, flint, chert, etc. It is a white, inert powder which gives " tooth " to paints but which has no hiding power. On account of its lack of hiding power it is used as a base for paste fillers for wood to form which it is mixed with a quick-drying varnish. Silica is found in the finely divided form as diatomaceous earth.

Titanium Dioxide. Various titanium pigments are used in paint. They include titanium-barium pigment, which consists of titanium dioxide and barium sulphate; titanium-calcium pigment, which consists of titanium dioxide and anhydrous calcium sulphate; and titanium-magnesium pigment, which consists of titanium dioxide and magnesium silicates with or without micaceous silicates. Titanium pigments have a very high hiding power, are chemically inert, are stable, and do not discolor. They may be used with all types of paint vehicles. If used alone on exterior surfaces, they *chalk* away rapidly, but this action may be controlled by combining with white lead and zinc oxide pigments and, still further, by grinding litharge into the paint. They are bright and neutral white in color.

Gypsum (Terra Alba), $CaSO_4 \cdot 2H_2O$. Gypsum when used as an extender pigment is made by grinding gypsum rock. It has good hiding power when mixed with water vehicle; so it is used in calcimines and is also used to dilute oil paints. Gypsum which has been burned at a temperature sufficiently high to drive off all of the combined water is used as an extender in Venetian red pigment.

China Clay or Kaolin (Hydrated Aluminum Silicate, Fuller's Earth). This is a very white amorphous powder produced by the weathering of feldspar. It has no hiding power and lacks tooth. It is used to prevent the settling of pigments in mixed paints and to improve the brushing quality. Kaolin is used as an inert base on which colors are precipitated in making the pigments known as lakes.

Color Pigments

Usually the various colored paints are made by adding a color pigment to white paint. Very dark paints, however, are made directly from the color pigments, linseed oil, turpentine, and a drier.

The more common color pigments are given in the following list. These pigments may be used singly or may be mixed to produce the color desired:

BLACK PIGMENTS

Lampblack
Gas or carbon black
Bone black
Charcoal black
Graphite (black lead or plumbago)

RED PIGMENTS AND LAKES

Indian red — dark purplish
Tuscan red — subdued crimson
Venetian red — brick red
English vermilion — scarlet
American vermilion (chrome red) — brilliant scarlet
Lakes — practically every shade of red, purple, and maroon

YELLOW PIGMENTS

Chrome yellow — deep orange to light yellow
Zinc chromate — light yellow
Barium chromate — light yellow
Ocher — pale yellow to olive
Sienna — brownish yellow

BROWN PIGMENTS

Burnt sienna — orange red
Raw umber — yellowish brown
Burnt umber — rich brown
Vandyke brown — walnut
Various mineral browns

GREEN PIGMENTS

Chrome green — pale yellow green to deep blue-green
Chrome oxide green
Emerald green
Verdigris — pale bluish green
Green earth — bluish green to bluish gray

BLUE PIGMENTS

Prussian blue — dark blue
Ultramarine blue — pure blue to green
Cobalt blue — greenish blue

These colors are commonly furnished ground in linseed oil but most of them may also be obtained in the powdered form.

Decorators' colors are a finer grade of colors, ground in oil, used in high-grade interior decorating. *Fine-glaze colors* are colors which do not hide the undercoats. They are ground in oil. *Water colors* are colors ground in water or "distemper," and are used for graining and the tinting of interior wall surfaces. Colors ground in japan are pigments with varnish as a binder and have a volatile thinner.

Red Lead. Red lead or oxide of lead is a brilliant red pigment used primarily on account of its very marked protective qualities. It is rarely, if ever, used as a color pigment in white lead. Red lead may be obtained as a powder or ground in linseed oil as a paste. The paint made from red lead and linseed oil forms a very tough and durable

surface which is extensively used as a priming coat to protect structural steel. It tends to darken when exposed to air containing sulphur compounds and to be whitened by other agencies but such defects are not serious because its principal use is as a first or priming coat.

Origin of Color Pigments. Many of the color pigments are *natural earths* consisting of earthy substances such as sand and clay mixed with such materials as the oxides of iron and manganese which provide the color. These materials are refined mechanically before being ready for use. Examples of this class of pigments are: yellow ocher, sienna, umber, and Venetian red (now made artificially). Burnt umber and burnt sienna are made by calcining or burning raw umber and raw sienna. The metallic or mineral browns are made by roasting native iron ores. Green earth is a natural earth commonly composed of silicates of magnesium and ferrous iron. Vandyke brown is made from decayed vegetation, and walnut stain from walnut hulls. Carmine is obtained from an insect named cochineal. Bone black is made from animal bones which have been burned and ground to a fine powder. Carbon black and lampblack are soot or carbon made by the incomplete combustion of gas, oil, resins, or fats.

Numerous color pigments are made by chemical processes which in many cases have replaced mineral or vegetable sources. Indian red and Venetian red were formerly supplied by natural earths or iron ores which were chiefly iron oxide but are now made by roasting green vitriol which is ferrous sulphate. English vermilion is mercury sulphide, and American vermilion is basic carbonate of lead, both of which are made chemically. Prussian blue is made by precipitating potassium ferrocyanide with ferrous sulphate. The pale blue precipitate thus formed is oxidized, forming the dark blue pigment. The pigments known as lakes are made chemically by the precipitation of a mineral such as barium sulphate, whiting, gypsum, or alumina in a solution of dyestuff, causing the mineral to be colored by the dye. Dyes in solution can not be used in paint, but by coloring the solid materials just mentioned the powdered pigments are obtained and are converted into paste by mixing them with oil, varnish, or water.

Aluminum. Aluminum powder is commercially pure aluminum in the form of fine, polished flakes. It is combined with a volatile paint thinner and a suitable fatty lubricant to form a paste suitable for paint pigment. The powder must have good *leafing properties*, i.e., must form a continuous brilliant film over the entire surface when mixed with a suitable liquid. The vehicle used with aluminum is linseed oil or varnish or a mixture of these. Aluminum paint is used over wood and metal surfaces. When applied to exterior structural steel, it is desirable

to use a priming coat of red lead, basic carbonate lead, zinc chromate, or other rust-inhibitive paint.

Other Metallic Pigments. See Bronze Paints, Art. 95.

ARTICLE 95. VARNISH, ENAMEL, AND LACQUER

Varnish. Varnish is defined as a liquid coating, containing no pigment, which flows out to a smooth coat when applied and dries to a smooth, glossy, relatively hard, permanent solid when exposed, in a thin film, to the air.[7] There are two general classes of varnish: spirit varnish and oil varnish. *Spirit varnishes* are composed of resin or a similar substance dissolved in a volatile liquid such as alcohol. *Oil varnishes* are composed of resins in solution in a drying oil such as linseed oil or tung or China wood oil, fish oil, perilla oil, oiticica oil, and dehydrated castor oil, a volatile thinner such as turpentine, and a drier.

Resins come from various sources such as the *fossil gums* formed from the gums given off by certain trees ages ago and now found buried in the ground; and *rosin* which is the residue resulting from the distillation of turpentine — a product resulting from the distillation of the resin from pine trees.

The most important resins are: the *copal*, which are fossil gums of widely varying quality and properties (that known as *zanzibar* being the best and most costly, and those known as *kauri* and *congo* being the most widely used); *dammar resin*, which is used extensively in spirit varnish; *rosin*, which is the residue left after turpentine has been extracted from balsum; and *lac*, which is used in making shellac.

Shellac is a resin obtained from stick lac, a resinous substance produced by the bites of an insect on the small twigs of several species of East Indian trees. The shellac is made by refining seed lac which is obtained from the stick lac. It is naturally orange in color and is known as *orange shellac* to distinguish it from *white shellac* which is made from the orange shellac by bleaching.

Oil varnish is made by melting the resin and adding to it a drying oil such as linseed oil or tung oil which has been heated. This oil may contain the drier or the drier may be mixed separately. The use of tung oil or China wood oil in varnish making is rapidly increasing. After the resin and oil are mixed and cooled a volatile thinner such as turpentine or benzene is added. The varnish is then filtered and stored. If the varnish is to be stored for a long enough period filtering is not necessary. Long storage improves the quality of varnish. Oil varnish is not simply a mixture of resin, drying oil, and a drier, but complicated chemical changes take place during the process of manufacture and storage. For this reason the details of the process are of utmost impor-

tance. Two varnishes made from the same materials may differ greatly in their properties.

Varnish containing a large proportion of oil is called *long oil varnish*, and varnish containing a small proportion of oil is called *short oil varnish.*

Oil varnishes are made to suit various conditions of service. *Spar varnish* is a long oil varnish made for exterior use and is highly resistant to weathering; *floor varnish* is resistant to wear and dries quickly; *rubbing varnish* is a short oil varnish which dries quickly so that it may be rubbed with powdered pumice stone and water to produce a rubbed finish; *flat varnish* dries without a gloss, producing a dull matte finish.

Varnish making is a highly developed and complex industry employing many special materials and processes known only to those who have developed them but the explanation just stated will give a general idea of the methods and materials used.

Spirit varnishes are divided into several classes: *Dammar varnish,* made by treating a special resin, known as dammar resin, with turpentine or a light mineral oil; *shellac varnish,* made by treating shellac with alcohol; and *asphaltum varnishes,* which are solutions of coal tar pitch in coal tar naphtha, or *oil varnishes* with a part or all of the resin replaced by asphaltum. Asphaltum varnishes may be made resistant to acids and fumes. They may dry simply by exposure to air or may be of a composition designed for drying by baking.

Enamels. Enamel may be defined as a kind of paint which flows out to a smooth coat when applied and dries to a smooth, glossy, relatively hard, permanent solid when exposed in a thin film to the air. An enamel always contains a pigment and has a considerable hiding power and color. Some enamels dry to a flat or eggshell finish instead of to a gloss finish. In general, enamels are paints with varnish as a vehicle and with various pigments to give the desired color. The colored pigments are usually added to a white enamel made from a white pigment such as zinc white. The surface produced by enamels is harder, smoother, and more resistant to wear than a paint surface. Enamel surfaces are naturally glossy owing to the varnish vehicle; but, if an eggshell finish is desired, turpentine may be substituted for some of the varnish, or by using a larger proportion of turpentine a flat enamel may be obtained. Lithopone is sometimes used to replace part of the zinc oxide as a pigment, especially in eggshell or flat enamels, because it tends to dull the luster of the enamel. The tendency of lithopone to turn gray in the sunlight is, of course, an objectionable feature. Asbestine is sometimes used on account of its property of holding pigments in suspension. Other inert extenders such as silica, whiting, and china clay are some-

times used to reduce the cost of enamel or improve its working qualities, but such adulterants should be used with caution. The undercoatings for enamel should preferably be flat enamels designed especially for that purpose, but paint is also used.

Lacquers.[1,2] The lacquer most commonly used on the interior finish of buildings consists of a nitrocellulose base to which certain gums, solvents, and pigments have been added. Nitrocellulose is also known as *pyroxylin*, so these lacquers are also called *pyroxylin lacquers*. Nitrocellulose is a combination of nitrogen and cellulose formed by treating cotton linters (short-fiber cotton) with nitric acid. The other ingredients are selected according to the kind of lacquer desired. Lacquers are similar to enamels in composition except that nitrocellulose is used instead of linseed oil.

Some of the gums used in lacquer manufacture are ester, kauri, manila, and congo, and some of the solvents are ethyl, butyl or amyl alcohol, amylacetate (banana oil), solvent naphtha and possibly benzene. Certain oils, such as castor oil, are used to make the film more plastic and thus reduce its tendency to crack due to expansion and contraction. These are called *plasticizers*.

Lacquers may be clear with a glossy or a flat finish like varnishes or they may be colored like varnish enamel. The pigments used are the same as those used in high-grade enamels.

The striking difference between lacquer and varnish or enamel is in the rapidity of drying. Lacquer dries by the evaporation of the very volatile solvent; but varnish dries by the relatively slow oxidation of the linseed oil, the evaporation of the turpentine in the varnish merely causing the varnish to set or thicken. Several coats of lacquer can be applied in a day. Since a large part of lacquer is volatile material the film formed by non-volatile constituents is relatively thin as compared with a varnish or enamel film.

Another difference between lacquer and varnish or enamel is in the hardness and tensile strength of the films. The lacquer film is hard and has great tensile strength whereas the varnish or enamel film is plastic and yielding. The lacquer film tends to shrink when drying, so forms a very smooth surface. It produces a hard, tough, waterproof surface that does not scratch and is easily cleaned.

Lacquer has certain peculiarities and unless it is intelligently selected and applied on a properly prepared surface poor results may be obtained. It has a relatively poor adhesion, is not elastic, and forms a thin film. Due to its lack of elasticity, lacquer is liable to crack when applied to wood because wood expands and contracts as its moisture content changes. For this reason most lacquers are not suited for use

on exterior woodwork. Metals are not affected in this way by moisture; so good results are more easily secured on metal than on wood.

Due to its hardness, durability, and resistance to wear, lacquer is suitable for the finishing of floors. A waxlike finish may be obtained if desired. Lacquer may be used on plaster walls which have thoroughly dried out. A priming coat on the walls is desirable before the lacquer is applied.

Surfaces which are to be lacquered must be absolutely dry and free from wax, grease, mineral oils, and dust or dirt, or moisture. Lacquer can not be used over old wax surfaces or over surfaces which have been cleaned with a paint remover which contains any wax.

The surface to which lacquer is applied must be smooth because lacquer will not cover up rough and uneven spots in the way that paint, varnish, and enamel will.

It is very essential that the undercoats used with the lacquer be properly selected. Ordinary oil paints contain too much oil for use under lacquers because the solvent in the lacquer reacts with the unoxidized oil and produces a rough irregular surface. Special paints with a minimum amount of oil are prepared as the undercoats for lacquer.

An oil stain or a spirit stain should not be used under a lacquer unless the lacquer has been thoroughly tested over that particular stain because the lacquer may bleach the stain. Shellac under lacquer destroys its toughness. If used, it should be as thin as possible.

Lacquers are divided into spraying, brushing, and dipping lacquers, depending upon their suitability for each of these methods of applying. The difference in these lacquers is in the solvents used. Those in spraying and dipping lacquers evaporate too rapidly for brushing. The ordinary brushing lacquer dries too quickly for use in covering large surfaces, so slow-drying lacquers are made using slow-evaporating oils. These oils are expensive so the slow-drying lacquers cost more than the ordinary brushing lacquers.

Brushing lacquer can be applied by ordinary brush or spray brush but spraying lacquer can be applied only with the spray brush. Excellent results are secured by spraying. Brushing lacquers contain solvents which act on the preceding coats; therefore, a painter must adopt different methods than those he uses with oil paint. He must work rapidly and not go back over surfaces which have just been lacquered, as by going over a surface several times he may soften the undercoats. Since lacquer is self-leveling on account of its tendency to shrink in drying, it is not necessary to go over a surface as much as in oil painting.

Bronze Paints. Bronze paints which are often used for painting radiators and other interior metallic surfaces are made from metallic pigments such as aluminum bronze (which is finely divided aluminum), copper bronze (which is finely divided copper), and other metals or alloys, with a vehicle of banana oil or a China wood oil resin varnish with a petroleum oil thinner.

A common vehicle for bronze paints is nitrocellulose lacquer called *bronzing liquid*, made by dissolving nitrated cotton (nitrocellulose) in amylacetate. This bronzing liquid is sometimes called *banana oil*, but this name applies only to amylacetate and not to the solution of nitrated cotton in amylacetate.

The bronzes are made by beating the metals into the thin leaf form with steam hammers, then converting them into the flaky powders by forcing the leaf through a fine mesh sieve, using a scratch brush, grinding in oil, removing some of the oil by water, and finally removing the remaining oil by pressing.

ARTICLE 96. STAINS AND WATER PAINTS

Wood Stains. Wood stains are used to color the grain of woodwork and to bring out its texture. They are classed as oil stains, water stains, spirit stains, and acid stains. *Oil stains* consist of pigments and oil to which a thinner such as turpentine or benzene has been added in sufficient quantity to enable the stains to penetrate into the wood; *water stains* are solutions of dyes in water; *spirit stains* are solutions of dyes in alcohol; and *acid stains* consist of acids, salts, and alkalies which are used to produce various effects by their action on wood.

Water stains and spirit stains raise the grain of the wood, whereas oil stains do not, but the water stains and spirit stains have a greater penetrating power than oil stains and produce a clearer finish. Spirit stains are also called *penetrating stains.* Pigments commonly used in oil stains are siennas, umbers, and ochers, and in some cases aniline dyes are used. Aniline dyes are used for coloring water stains and spirit stains.

The acid stains include many materials which are not acids. These materials include nitric acid, hydrochloric acid, ammonia, potassium bichromate, copper sulphate, and many other chemicals which act on woods, such as oak, which contain tannic acid to change the natural color and produce a stained appearance.

Varnish stains are thin varnishes to which a coloring material has been added. They differ from enamels chiefly in that they are transparent and do not hide the grain of the wood.

Shingle Stains. Shingle stains are intended to preserve and color shingles but do not bring out the grain. They are usually oil or spirit stains with creosote oil added as a preservative.

Water Paints. The paints having water as a vehicle are: whitewash, calcimine, and cement wash. They are sometimes called *distemper paints.*

Whitewash is made from quicklime slaked with water or from hydrated lime, which is lime which has been slaked at the mill. Water is added to the slaked lime to make it thin enough to apply with a brush. Flour, skimmed milk, glue, molasses or other substances may be added to increase its adhesion. Preservatives such as salt or formaldehyde should be added to keep these substances from spoiling. Whitewash is the cheapest paint available and has desirable sanitary properties. It may be tinted by the use of pigments.

Calcimine is made from whiting, which is powdered lime carbonate; water, some material such as glue or casein as a binder which will hold this mixture to the surface to which it is applied; and a pigment to give the desired color. Calcimine may be prepared by the painter or may be purchased from manufacturers in a powdered form ready for the addition of water. In general, the prepared calcimines are mixed with cold water to form cold-water calcimines or cold-water paints, but some require boiling water and are called hot-water calcimines. The pigments used to color calcimine are the same as those used for oil paints but they are furnished in the powdered form and are called *distemper colors.*

Cement wash is simply a thin grout made of portland cement and water and of such a consistency that it can be applied with a brush. Fine sand is sometimes added. This wash may be colored if desired and with some tints it is desirable to use white portland cement. Paints consisting of about 2 parts of portland cement to 1 part of lime are on the market.

ARTICLE 97. MISCELLANEOUS PAINT MATERIALS

Floor Wax. Floor wax is made from beeswax and paraffin wax with other materials such as turpentine and gasoline added to make a workable mixture.

Putty. The putty used in connection with painting may be whiting putty or white lead whiting putty. *Whiting putty* is a mixture of finely powdered natural chalk, called whiting, and linseed oil. *White-lead whiting putty* has the same composition as whiting putty except that about 10 per cent of the whiting is replaced by white lead. Putty is

given the desired color by adding a minimum amount of colored pigments. Putty hardens by the oxidation of the linseed oil.

Putty is used for filling knot holes, dents, nail holes, cracks and other defects in wood surfaces preliminary to painting. It is applied after the priming coat of paint in order that too much of the linseed oil in the putty will not be absorbed by the wood. Putty is also used to hold glass in window sash and doors, as explained in Art. 86. Putty used on steel sash must be of special composition.

Fillers. Fillers are commonly used on open-grained woods, such as oak, chestnut, and ash, to fill the pores before applying varnish. Fillers are of two classes: paste fillers and liquid fillers. They should not conceal the grain of wood or dull stained woods and so should be as nearly colorless and as transparent as possible.

Paste fillers should preferably consist of silex, which is powdered silica or quartz, and of a quick-drying varnish mixed in proportions which will yield a paste. Barytes, clay, whiting, and gypsum are used to a certain extent on account of their cheapness but they give an inferior product. Paste fillers may be colored, if desired, by the addition of pigments or stains. Paste fillers are thinned with turpentine before using and are rubbed into the wood with short stiff brushes. After the filler has set for a few minutes the part which has not been taken up by the wood is removed.

Liquid fillers may be paste fillers which have been thinned, they may be thin varnishes, or they may be a mixture of gloss oil, linseed oil, and a pigment such as asbestine, or china clay. The latter type is unsatisfactory. Shellac in alcohol is frequently used as a liquid filler. Most liquid fillers are designed for use on close-grained woods. Paste fillers are more commonly used than liquid fillers.

Pumice Stone. This stone of volcanic origin, imported from Italy, is used in the form of a gray powder for rubbing paint, varnish, and enamel to remove the gloss and form a smooth surface. It is used with water or a non-drying oil. Pumice stone is available in several grades of fineness.

Rottenstone. This white powder is finer than pumice stone, but is used in the same way. It produces a finer finish than pumice stone. Several grades of fineness are available.

Sandpaper. Sandpaper is made by gluing ground flint to manila paper. It is used for smoothing the surface of lumber and of paint, varnish, or enamel, or removing paint, varnish or enamel. Sandpaper is available in several grade of fineness.

Steel Wool. Steel wool consists of fine shreds of steel matted together for use in the same manner as sandpaper. It is available in several grades of fineness.

Curled Hair. Curled hair is usually horsehair. It is used to rub the surface of varnish or enamel to reduce the gloss.

Excelsior. Excelsior is shredded wood. It is used in the same manner as curled hair.

ARTICLE 98. MIXING AND APPLYING

Mixing. White oil paint forms the basis for oil paints of all colors. In mixing white lead paint, the white lead, which comes mixed with linseed oil to form a paste, is first "broken up" by adding linseed oil, a little at a time, and working it in with a paddle. When the paste has all been converted into a heavy liquid of uniform consistency, it is thinned the desired amount by adding more linseed oil. If linseed oil is added in large amounts to the paste before it is broken up, the thinned paint will contain lumps of white lead which are difficult to break up. In mixing lead-zinc paints, the white-lead and zinc-white pastes are broken up separately and mixed after each has been thinned to about the desired consistency. Driers are preferably added to the white paint after the paste has been broken up, but before it has been thinned. Colored paints are made by adding the proper color pigments to white paint. These pigments are first broken up and thinned with linseed oil and turpentine. The lumps and skins are removed from paint by straining through fly screen or cheesecloth fastened over the top of a pail. Black paint and red-lead paint are made from the pigments without the use of a white paint base.

Ready-mixed or prepared paints are on the market. To insure good quality, prepared paints made by reliable manufacturers should be purchased. If after opening a can of prepared paint, it is found that the pigment has settled to the bottom forming a thick paste, the liquid portion should be poured into another can. The paste should then be stirred with a paddle, and the liquid slowly added to the paste, the stirring being continued. Paint stores have vibrating machines in which unopened cans of paint can be placed, when purchased, to mix the pigment and liquid. Prepared paints are available in a great variety of compositions and colors to suit various conditions of service.

Enamels are not usually prepared by the painter since better results are obtained with enamel prepared by the manufacturer. Pigments which have settled to the bottom of the can are broken up in the same manner as described for prepared paints.

Varnish is manufactured ready for use and its composition should not be altered by the painter. It is not simply a mixture, like paint, but is the product of chemical reactions which can not be duplicated on the

job. Small amounts of turpentine are sometimes added to make varnish thinner but this practice should be avoided if possible except where thin varnish is used as a filler.

Preparation of Surface. For the best results, the material to be painted should absorb the vehicle to such an extent that a sufficient penetration to anchor the paint film will be secured. For reasons of economy, however, excessive absorption is undesirable. Surfaces which are wet, or covered with a coating of oil, grease, dust, or any foreign matter which will interfere with the penetration or adhesion of the paints or varnishes are obviously not in condition to receive the paint or varnish. Some materials contain substances which react with some of the constituents of the paint or varnish and eventually destroy them. Under these circumstances a treatment is necessary to remove, to seal, or to neutralize these substances so that they will not be harmful. Considering only the adhesion of the paint, it is desirable that wood and metal surfaces be exposed to the weather for at least a short period before painting. This raises the grain of the wood slightly and removes the oil film which may be on the metal and results in better adhesion. Weathering, however, may cause wood to shrink, crack, and warp, and steel to rust; so exposure to the weather may be undesirable from this point of view.

White pine, poplar, redwood, maple, birch, and Douglas fir are excellent bases for paint, varnish, and enamel and require no special treatment. They are close-grained and thus require no filler and absorb the paint readily enough to insure the anchorage of the paint film but not in excessive amounts. White pine and poplar are not often varnished because their grain is not attractive. Birch takes stain exceptionally well.

Hard or yellow pine and cypress are filled with pitch or gum to such an extent that it is very difficult to make surface coatings adhere to them. In extreme cases it may be necessary to treat the surfaces of these woods with benzol, solvent naphtha, or turpentine just before application of the paint or other coatings. These materials tend to dissolve the gum or resin enough to increase the adhesion of the paint.

Oak, chestnut, and walnut are open-grained woods which require a filler. The filler fills the grain, reduces the absorption or "suction," and gives an even surface to receive paint, varnish, or enamel. Oak and walnut are usually varnished and are rarely painted or enameled.

Sappy wood and knots should be treated with a solution of shellac in alcohol to keep the resin from destroying the paint film by dissolving the oil. This operation is known as *knotting*. It is particularly important on surfaces exposed to the sun.

Concrete and plaster surfaces which have not aged for long periods

may contain free lime which will react with linseed oil to form a soap. This soap is readily dissolved by rain leaving only the pigment without a binder to hold it in place. The harmful effect of the free lime may be overcome by treating the surfaces with a wash consisting of zinc sulphate and water. After this coating has dried for two or three days the surfaces may be painted or enameled. Before painting, it is desirable to go over the surface with a brush to remove any crystals which have formed. Other chemicals are used, but zinc sulphate is the most common. Concrete surfaces absorb paint to such an extent that it is desirable to use a filler to decrease the absorption or " kill the suction." The zinc sulphate accomplishes this to a certain degree but it is usually desirable to use the filler in addition to the zinc sulphate. Special fillers for concrete surfaces are on the market.

The treatment should not be so effective as to do away with all of the absorption for in that case the paint would not adhere firmly. If plaster walls are to be calcimined, the absorption is usually decreased by using a coat of *size* to decrease the suction. The glue size usually used consists of a solution of glue and water. Sizes are sometimes used on walls which are to be painted, but this practice is not desirable.

Metal surfaces are difficult to paint satisfactorily. New surfaces may be coated with a thin film of oil or may be covered with mill scale and, in the case of iron and steel, old surfaces may be rusted. The oil may be removed by scrubbing with soap and water or wiping with a cloth moistened with benzene. Rust, mill scale, etc., are removed by scraping, wire brushing, or sandblasting. The oil film which covers new galvanized steel sheets is treated with a thin coating of copper chloride, copper acetate, or copper sulphate. Another solution which is used consists of equal parts of copper chloride, copper nitrate, sal ammoniac, and hydrochloric acid. A weak solution of acetic acid is extensively used and may give satisfactory results. These coatings are allowed to stand for several hours and are then washed with clean water and permitted to dry before the priming coat is applied.

Priming Coat and Other Undercoats. The first or priming coat for wood surfaces should be thin enough to penetrate into the wood so as to insure satisfactory adhesion and it should dry flat to provide a good base for the next coat. For these reasons, the proportion of turpentine is relatively high, particularly on such woods as hard pine and cypress which do not absorb paint readily. The materials used in the priming coat should be the same as those in subsequent coats but the proportions may vary. The best priming coat on metal is probably a red lead and oil paint. The priming coat for enamel finish may be either enamel or oil paint. It is important properly to prepare the surface to receive the priming coat and to use care in applying this coat.

After the priming coat is applied all nail holes, cracks, and similar surface defects should be filled with putty.

For the best results, it is desirable to sandpaper lightly each coat of paint, enamel, and varnish before the next coat is applied. This removes the rough spots caused by dust particles and provides a better surface for the adhesion of the next coat. The finest sandpaper should be used, taking care not to cut through the film. After sanding, surfaces should be wiped clean. Curled hair and excelsior are sometimes used instead of sandpaper to remove the gloss on varnish. The coat which precedes the finish coat may be rubbed with pumice and water instead of sandpaper to secure the highest grade of finish for enamel or varnish.

Ample time must be allowed for each coat to dry before the next is applied. For the best results it is desirable to strain the paint, varnish, or enamel several times during a painting operation. The brushes must be kept clean.

At least two undercoats should be used for paint and varnish and three or four undercoats for enamel.

Finishing Coat. Paint may have a gloss, an eggshell finish, or a flat finish, depending upon the amount of turpentine and upon the pigments used. A small amount of varnish is sometimes added to the finishing coat to increase the gloss. Outside surfaces should have a gloss finish because this is not so easily soiled, but an eggshell or flat finish is usually more attractive for interior work.

Enamels and varnishes will naturally have a gloss finish but those which dry without gloss are extensively used. A dull finish may be produced by rubbing the final coat of gloss finish with a very fine steel wool or with pumice stone in water or a non-drying oil. This is usually done with a felt pad but a brush with the bristles cut short may be used for quicker but less satisfactory results. After a surface has been rubbed to a smooth dull luster it is polished with rottenstone and a non-drying oil. After the polishing is completed the surface is cleaned with a soft cloth dampened in benzene and rubbed with a chamois-skin.

The surface of oil paint is sometimes finished by *stippling*. This is done by striking the wet paint many blows in rapid succession with a brush with stiff bristles. Tiny closely spaced indentations are made in the surface of the wet paint giving it a flat appearance when dry.

Painted surfaces may be made to resemble oak or other woods with a prominent grain by a process known as *graining*. This is done by first painting the surface a light color. After this coat has dried, paint of a darker color is applied to the surface. While this paint is still wet a leather or steel graining comb, a rubber grainer, a brush, or a cloth is

drawn over the surface in such a way that it removes a part of the dark paint, leaving streaks or patterns to resemble the grain of wood. The choice of colors and the pattern of the grain depend upon the wood which is being imitated. By this process, wood without grain, such as white pine or poplar, is made to resemble such woods as oak. Metal surfaces are also made to resemble wood surfaces.

A *wax finish* may be applied to wood with or without undercoats of varnish or shellac. If no varnish or shellac is to be used the wax is applied to the wood after it has been filled. After the wax has dried it is polished with a weighted brush for floors or with a flannel for wood trim. More than one coat is usually applied. Better results can be secured if one or two coats of varnish or shellac are applied to the wood after it has been filled and before waxing.

Weather Conditions. To secure good results, paint or varnish should not be applied in damp humid weather nor at times when the temperature is below 50 deg. fahr. For varnish and enamel, the temperature should be above 60 deg. and preferably above 70 deg. fahr. Every precaution should be taken to keep dust or dirt from blowing on paint, varnish, or enamel before they are dry.

Methods of Applying. The usual method of applying paint and varnish is with a brush, but small articles may be coated by dipping them in vats of paint, or varnish, and nearly all classes of work may be done by air spraying.

The best brushes are made from the bristles of swine raised in China and Russia but horsehair is sometimes used as an adulterant or to make brushes stiffer. The bristles of brushes are set in cement or rubber.

Spraying is carried on by paint-spraying machines which by means of compressed air force the paint against the surface to be painted. The power for operating these machines is furnished by gasoline engines or electric motors. The compressed air is forced into a tank called an air receiver and the paint is placed in the paint tank. Compressed air forces the paint through a hose to the spray gun which the operator holds. In order to form a spray of the paint and not a stream, compressed air is supplied to the air gun through another hose. This air comes in contact with the paint, forming a spray which is forced against the surface to be painted. The whole apparatus is controlled by suitable valves to produce the desired results. The spray is turned on and off by a trigger on the gun. The gun is moved over the surface to be painted and is kept 6 or 8 in. away from it. The air spray is effective where large areas are to be covered but is also used on small articles. Spraying requires somewhat more paint than hand brushing but the labor cost is less for work to which spraying is adapted.

ARTICLE 99. OTHER PROTECTIVE COVERINGS FOR METAL

Methods. Steel or iron may be protected from corrosion by coating them with protective coverings of zinc, as in the *galvanizing* and *sherardizing processes;* with a coating of tin, as in *tin plating;* an alloy of lead and tin, as in *terne plating;* a coating of nickel, as in *nickel plating;* a coating of chromium, as in *chromium plating;* or a coating of copper, as in *copper plating.* Nickel plating is also applied to copper and brass to give the desired surface finish. The surface of steel or iron is protected by cadmium in the *Udylite process,* which is not extensively used. Vitreous enamels are used on bath tubs, sinks, etc.

Galvanizing Process.[9] A coating of zinc may be placed on the surface of steel or iron by three different processes: the hot-dip process, the sherardizing process, and the electrolytic process. In all of these processes it is first necessary to clean the surface of the iron or steel by pickling in acid to remove all scale or oxide.

In the *hot-dip process* the metal to be treated is passed through a bath of molten zinc which forms a coating of zinc on the surface, the thickness of the coating depending upon the temperature of the bath, the time in the bath, and the extent the sheets are wiped after coating. This process with modifications is used for sheet metal, pipe, wire, and articles of various shapes. It is practically the only process used for sheet metal and pipe.

The *sherardizing process* is used primarily for coating small irregular-shaped articles and consists of heating the articles in a revolving iron drum with powdered zinc. The zinc is volatilized and deposited on the iron forming a coating which conforms sharply to the original lines of the object being coated.

The *electrolytic process* is usually applied to small irregular-shaped articles. The coating is applied by depositing zinc electrolytically from a solution of zinc salts.

Plating Processes. In *tin plating,* iron or steel sheets which have been thoroughly cleaned by pickling in acid are passed through baths of molten tin and rolled to remove the surplus tin. *Terne plating* is carried out in the same way except that the baths contain a molten mixture of tin and lead.

Nickel plating and *copper plating* are usually done by the electrolytic process. The article to be plated is made the cathode. The anode is composed of the same material as the plating. The anode and the cathode are immersed in a bath containing a solution of a nickel or copper salt depending upon the kind of plating. The metal is deposited on the cathode and the anode decreases a corresponding amount, the composition of the bath remaining constant. It is necessary to copper

plate steel before it can be nickel plated. Chromium plating, for decorative purposes, consists of a very thin coating of chromium applied to a nickel-plated surface. If applied over steel, the nickel serves to protect the steel from corrosion and the chromium protects the nickel from tarnishing and produces a high gloss without polishing.

Vitreous Enamels. In applying *vitreous enamels* to cast iron or steel, the metal is first thoroughly cleaned by pickling in acid or in some other way. The first coat, consisting principally of silica from sand or quartz, alumina from clay, and lime, is applied wet. After this coat has dried, it is heated in a furnace to fuse the enamel. The composition is such that the first coat is usually blue. The metal is removed from the furnace and a powder which will form a white enamel is sifted on the surface. The metal is then heated again until the second coat of enamel is fused. This process is repeated until the desired number of coats is obtained. Enamel iron and steel are used for bath tubs, sinks, and other sanitary ware.

REFERENCES

1. COLFAX, W. S., JR.: "Lacquers, Composition and Uses," Handbook, Illinois Society of Engineers, 1927.

2. "Proper Use of Lacquer," Architectural Forum, Vol. XLVII.

3. "Paints and Varnish," Circular 69, National Bureau of Standards, 1917.

4. VANDERWALKER, F. N.: "Painting and Decorating," International Association of House Painters and Decorators.

5. "Symposium on Paint and Paint Materials," American Society for Testing Materials, 1935.

6. FULLER, WAYNE R.: "Inert Materials for Admixture with Paint Pigments," Bulletin, American Society for Testing Materials, August, 1940.

7. Standards of American Society for Testing Materials, a Triennial Publication.

8. SIMONDS, HERBERT R.: "Finishing Metal Products," McGraw-Hill Book Co., 1935.

9. "Materials for the Household," Circular 70, National Bureau of Standards, 1917.

10. "Nature of Portland Cement Paints and Proposed Recommended Practice for Their Application to Concrete Surfaces," Journal of American Concrete Institute, June, 1942.

SUPPLEMENTARY DEFINITIONS *

Areaway. An open subsurface space, adjacent to a building, used to admit light or air or as a means of access to a basement or cellar.

Attic Story. *See* Story.

Backfill. The replacement of excavated earth into a pit or trench or against a structure.

Basement. A story partly underground, but having half its clear height below grade. *Cf.* Cellar.

Bay. One of the intervals or spaces into which a building plan is divided by columns, piers, or division walls.

Bulkhead. (1) A structure above the roof of any part of a building, enclosing a stairway, tank, elevator machinery, or ventilating apparatus or such part of a shaft as extends above the roof. Sometimes defined as synonymous with Penthouse. (2) In northern states, a sloping door or doors affording entrance to a cellar from outside a building.

Cellar. A story having half or more than half of its clear height below grade. *Cf.* Basement.

Court. An open unoccupied space bounded on two or more sides by extension walls of a building or by exterior walls and lot lines. *Cf.* Shaft and Well.

Datum. An assumed horizontal reference plane used as a basis for computing elevations.

Elevation. (1) Altitude relative to a given datum. (2) A scale drawing of the upright parts of a structure.

Facade. The face of a building.

Grade. (1) The form of the surface of the ground as it exists (natural) or as it is made by cutting or filling (finished). (2) The slope of a ground surface or any line thereon. (3) The elevation at a given location.

Grading. Modification of the ground surface by cuts or fills or both.

Half-Story. *See* Story.

Penthouse. (1) An enclosed structure above the main roof line of a building other than a bulkhead, usually designed for use as a dwelling or for other human occupancy. *Cf.* Bulkhead. (2) A roof structure, not used for housing any utilities, appliances, or operating equipment or apparatus (Building Code for California 1939). (3) Any structure erected above the roof of a building, for the purpose of enclosing stairways to the roof, elevator machinery, water tanks, ventilating apparatus, exhaust chambers, or other machinery or other building equipment machinery (Philadelphia Building Code).

Plan. A drawing representing any one of the floors or horizontal crosssections of a building or the horizontal plane of any other object or area. *Cf.* Elevation.

Plot. (1) A parcel of land or an assemblage of adjacent parcels of land in a single unit. (2) A relatively small area of land.

Plot Plan. A layout showing present or proposed developments on a plot of ground. *Cf.* Site Plan.

Shaft. A vertical enclosed space passing through at least one floor and used for ventilation, light, elevators, wiring, piping, or similar purposes. *Cf.* Court and Well.

Site Plan. A layout showing the functional organization of a proposed improvement. *Cf.* Plot Plan.

Story. The part of a building comprised between any floor and the floor or roof above. *Attic Story.* That part of a building situated wholly or partly within the roof frame, or between the top-story ceiling and the roof, usable for storage but not finished for habitation. *Half Story.* That part of a building situated wholly or partly within the roof frame, finished for habitation.

Sub-Cellar. A cellar under a cellar.

Trim. The finish materials in a building, such as moldings applied around openings (window trim, door trim) or at the floor and ceiling of rooms (baseboard, cornice, picture molding).

Well. An open, unoccupied area bounded on all sides by walls of a building, passing through at least one floor, commonly used to supply light and air for stairways and minor interior spaces. *Cf.* Court and Shaft.

*Largely from "A Glossary of Housing Terms," Building Materials and Structures Report 91, National Bureau of Standards.

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